UNIVERSITY OF ALBERTA

FRAMEWORK FOR IMPROVING PRODUCTIVITY OF DRAINAGE OPERATIONS MAINTENANCE CREWS

©

BY

AMANTE ALBERT CAMAT AGBULOS

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requirements for the degree of Master of Science

in

Construction Engineering and Management

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

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Date: May 22, 2003

ABSTRACT

The City of Edmonton's Drainage Operations Branch oversees the inspection, maintenance, and repair of the city's drainage network covering an area of over 700 km^2 to serve the city's population of over 600, 000. The maintenance activities consume a large amount of funding and, therefore, are sensitive to any improvement in the maintenance crews' productivity. This study focuses on the development of improved work methods and engineered productivity standards for selected Branch maintenance crews. The application of the industrial engineering work measurement, lean production theory, and simulation analysis was used to capture current work methods, generate and test alternative methods, and develop the new standards. The focus of this research is to demonstrate the effectiveness of the methodology in enhancing the productivities of sewer maintenance crews by developing and establishing standards utilizing current Work Study Analysis, lean production principles, and simulation.

This thesis is dedicated to Wendy Deauna for her love, affection, and encouragement to successfully complete my graduate degree,

And

To my parents, Amante and Ofelia Agbulos for their encouragement and continued support throughout my entire education.

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CHAPTER 1: INTRODUCTION

1.1 RESEARCH MOTIVATION

The City of Edmonton's Drainage Operations Branch is responsible for maintenance of sewage pump stations, stormwater facilities, bylaw enforcement, pollution control, and the handling of public complaints involving the drainage system. The network covers an area of over 700 km^2 to serve Edmonton's growing population of over 657, 000. In 1999 an efficiency audit was conducted by the Office of City Auditor (OCA) on selected City of Edmonton drainage operations maintenance activities; the goal of that audit was to measure and assess the reasonableness of the drainage section's efficiency and productivity standards for fieldwork, as well as justifying work crew size and levels of supervision. The OCA determined that most of the crews were appropriately staffed but performed their designated maintenance activities inefficiently. Moreover, productivity standards have not been formally developed and used in a meaningful manner for day-to-day control of operations and performance measurement. However, management in the City's Drainage Operations division has made significant progress in the area of benchmarking by participating in a Canada-wide comparative study of municipal drainage operations. In addition, the audit discovered that a significant amount of annual budget could potentially be saved by altering some of the crews' work methods as well as developing productivity standards. This Work Analysis Study involving the City of Edmonton's Drainage Services Branch, the OCA, and the University of Alberta's Construction Engineering and Management Group was conducted to develop improved work methods, productivity standards, standards for material and equipment costs, and to conduct a physical demands analysis. This project is one of the initiatives being undertaken in Drainage Services and Drainage Operations to improve efficiency within the branch to meet the City Council directive of achieving a minimum of 1.5% efficiency improvement.

This study focused on six activities that account for 25% ($3 million) of the total drainage operations budget. These six selected work activities are: (1) cleaning mains by low pressure flushing, (2) cleaning mains by high pressure flushing, (3) scheduled mechanical cleaning of catch basins, (4) inspecting mains by televising, (5) commercial establishment investigation, and (6) service line rodding and televising. The study was carried out using Work Analysis Study and simulation methodologies to improve the crews' performance. The low pressure flushing activity was selected as the pilot study to evaluate the proposed changes and methodologies. The research resulted in the development of a productivity standard based on current work methods as well as examining and modifying the work method, as a result, the crews' productivity (i.e. the number of metres flushed per shift) had increased by 29%, i.e. from 2194 m/day to 2820 m/day. As of November 2002, 3 of the 5 crews met or exceeded the standard regularly.

The pilot study has provided Drainage Operations management with the tools and techniques that are required for successful productivity improvement and implementation to the other drainage operations crews. Each maintenance activity (except for low pressure flushing) will have their process investigated for potential changes to their existing work methods and to evaluate the impact of these changes on the productivity of these crews. Ultimately, the application integrating the lean theory concepts to the general purpose simulation (GPS) models provides the framework to validate the integration of the two methodologies: lean principles and simulation.

1.2 RESEARCH OBJECTIVES & METHODOLOGY

The main objective of this research is to develop and implement productivity standards for selected work crews. The secondary objective of this research is to integrate lean principles with simulation methodology. Having successfully implemented the methodology with the low pressure flushing activity from the Work Analysis Study, the remaining crews will be examined to determine the impact on productivity upon the development of productivity standards and with the application of lean theory using simulation. The objectives will be achieved as follows:

- Develop a precise understanding of lean theory
- Investigate the application of lean theory to drainage operation crews
- Gain knowledge of current industrial engineering performance measurement
- Obtain a sound understanding of general purpose simulation methodology
- Adapt lean theory to simulation modelling

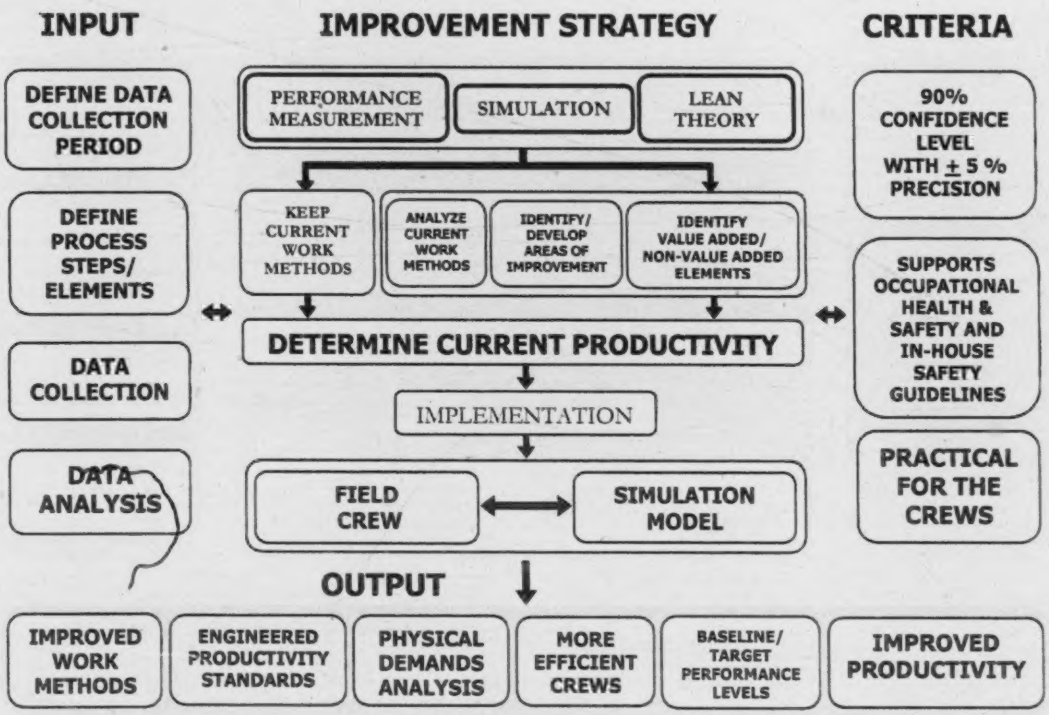

INPUT
IMPROVEMENT STRATEGY
CRITERIA
DEFINE DATA COLLECTION PERIOD
DEFINE PROCESS STEPS/ ELEMENTS
DATA COLLECTION
DATA ANALYSIS
PERFORMANCE MEASUREMENT
SIMULATION
LEAN THEORY
KEEP CURRENT WORK METHODS
ANALYZE CURRENT WORK METHODS
IDENTIFY/ DEVELOP AREAS OF IMPROVEMENT
IDENTIFY VALUE ADDED/ NON-VALUE ADDED ELEMENTS
DETERMINE CURRENT PRODUCTIVITY
IMPLEMENTATION
FIELD CREW
SIMULATION MODEL
90% CONFIDENCE LEVEL WITH ± 5 % PRECISION
SUPPORTS OCCUPATIONAL HEALTH & SAFETY AND IN-HOUSE SAFETY GUIDELINES
PRACTICAL FOR THE CREWS
OUTPUT
IMPROVED WORK METHODS
ENGINEERED PRODUCTIVITY STANDARDS
PHYSICAL DEMANDS ANALYSIS
MORE EFFICIENT CREWS
BASELINE/ TARGET PERFORMANCE LEVELS
IMPROVED PRODUCTIVITY

Figure 1: Overall research flow chart

Figure 1 illustrates the main process of the proposed methodology. The research methodology consisted of five phases: 1) performance rating training, 2) literature review of industrial engineering performance measurement, lean production theory, and simulation, 3) data collection and analysis, 4) general purpose simulation application, and 5) determine the effectiveness of developing productivity standards as well as investigating the impact of the application of lean concepts to current work methods using simulation.

The first phase involved acquiring knowledge in industrial engineering performance rating through the following three stages of orientation training and procedures: (1) Al Rose Industrial Engineering Supervisory Training program, (2) literature review, and (3) viewing the City's video archive of drainage operations. Figure 2 illustrates the actual 'conservative rating' graph resulting from the author's orientation program. Depending on the personality, individuals can be categorized as either tight, loose, extreme, or conservative (see Figure 3). The outcome of the training is the skill to rate workers at a consistent level during the data collection period as well as in the determination and evaluation of 'normal' time spent on an activity, for example (see Section 3.4.2 for further discussion).

The second phase consisted of reviewing the state of the art literature on current industrial engineering performance measurement techniques, lean theory, and simulation. This portion of the research develops a greater understanding of the methods of measuring and modifying work, the principles fundamental to lean theory, and simulation methodology. Several applications of these concepts were investigated and provided insight on approaches to accomplish the objectives specified previously.

The third phase involved the data collection by observing the working crews and evaluating the historical data; in order to perform the data analysis. The time study, as described in Sections 2.3 and 3.4, was the prime method used for gathering data. The simplicity, effectiveness, and versatility are characteristics of the time study justifies why the method was chosen. Using specialized, "off the shelf" time study software such as Timer Palm™ enhanced the data manipulation process (see Section 3.5.7 for details) by enabling easy and effective data collecting as well as enabling a quick and accurate data analysis. Each work activity in drainage operations maintenance was observed for a full shift at a time over a 3-month period and subsequently analyzed to develop productivity standards using spreadsheets. This phase overlaps with the fourth phase.

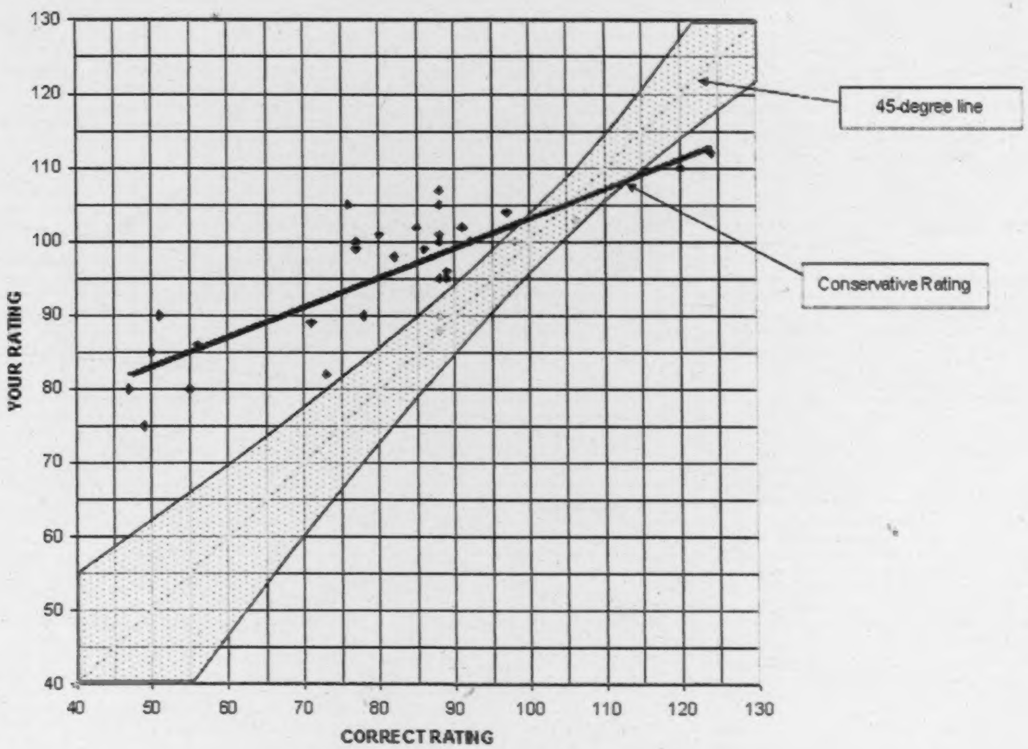


Figure 2: My results – 'conservative' rating type

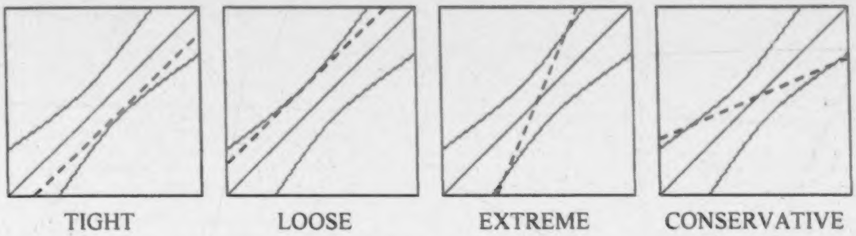


Figure 3: Performance rating types

The fourth phase of the study focuses on the use of General Purpose Simulation (GPS) models developed by the Construction Engineering and Management (CEM) Group. These models were created in conjunction with the Work Analysis Study involving the City of Edmonton Drainage Operations Branch, the Office of the City Auditor, and CEM Group at the University of Alberta. This research used simulation as the primary means of integrating lean principles to the current work methods of the crews. The final phase of the study is to determine if the development and establishment of productivity standards produced effective gains in productivity and whether or not the application of lean theory provided any productivity improvement for the crews of drainage operations using the GPS models.

1.3 THESIS ORGANIZATION

This thesis is organized in five chapters. Chapter 2 provides a summary of lean theory principles and time study in construction, as well as the state-of-the-art in GPS methodology. Chapter 3 reviews the current work performance measurement techniques used by industrial engineers. An inside look into work measurement, work simplification, time study and effective execution, as well as a fundamental look into ergonomic theory is demonstrated. Chapter 4 includes an assessment of the GPS models developed for the Work Analysis Study and reveals how the models are structured. The objectives and application of lean theory to the models is presented. The impact of developed and established standards as well as the application of lean principles and simulation models to the productivity of the drainage operations work activities is evaluated. A summary of the results, limitations to the current study, as well as alternatives requiring extensive work not implemented using simulation finalizes the chapter. Chapter 5 includes the conclusions, contributions, and recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a summary of the state-of-the-art in the following areas:

1. Lean principles,
2. Work performance measurement using time study analysis methodology, and
3. Simulation.

Section 2.2 presents a summary of current lean-principle applications as well as the development of lean-thinking within the construction industry. Section 2.3 reviews the current use of time study as a method of data-gathering and the extent of utilization in construction. Section 2.4 presents the state-of-the-art in general purpose simulation.

2.2 LEAN-THINKING PRINCIPLES

2.2.1 OVERVIEW

The principles of lean-thinking were adapted from lean production philosophy developed for Toyota led by engineer Taichi Ohno (Howell, 1999). The term "lean" was introduced by the research team working on international auto production to reflect both the waste reduction characteristic of Toyota's production system and to contrast it with craft and mass forms of production. Ohno advocated the shift of attention from craft production (worker productivity) and mass production (machine productivity) to the entire production system. The underlying philosophy of lean production theory is the avoidance, elimination, or reduction of waste. Waste is recognized by lean production theory as performance criteria, i.e. failure to meet the unique requirements of a client. In other words, time, space, or material used in the performance of an activity that does not directly contribute value to the finished product. Industrial engineering defines waste as a non-value added work step classified as being handling, transportation, delay, inspection, storage, and rework. A value added work step is classified as either being an operation step or a combined operation and inspection step for which the basic work performed is of value to the customer. Koskela (1992) summarizes lean production theory in three main principles: (1) Eliminate or reduce all activities that do not add value to the final product, (2) pull material through the process (instant delivery of required materials), and (3) reduce variability by controlling uncertainties within the process. There are many perspectives to defining and identifying lean theory, however, they all share the same fundamental idea that lean-thinking is to provide the customer with quality products while satisfying the requirements of the customer and maintaining no immediate inventories (reducing waste). Generally, the construction industry has rejected the ideas of lean production due to the traditional nature of those working within construction. Nonetheless, there has been extensive research done to support the benefits of lean production theory. The following section describes presents the state of the art literature of the research that has been conducted for lean production theory applied in the construction industry. Lean construction (or production), work design, methods engineering, methods study, or work simplification are used synonymously since the same fundamental principles apply (see Table 1).

Table 1: Summary of principles of lean-thinking

PRINCIPLE	*ACTION TAKEN*
Identifying value-adding and non value-adding activities. Reducing share of non value-adding activities (also called waste).	• Eliminating various steps from a process. • Combining two or more process steps. • Minimizing the time duration of associated process steps.* • Simplify the motion of associated process steps.* • Change sequence of process steps or flow of activities.
Pursuing perfection, identifying & delivering value to customer	• Improving resource availability. • Improving resource accessibility. • Providing the right resources at the right place and time meeting requirements with no inventory. • Eliminating process waste & improving resource availability and accessibility.
Create continuous work flow.	• Identifying & eliminating chokepoints (megadelays). • Using technology, especially computer-based information technology, to improve process flow. • Improving process layout. • Integrating process activities.
Using cross-functional work teams focused on completing a specific work activity.	• Organize personnel around work activities. • Cross train personnel when possible for associated activity tasks. • Use cross-functional teams at interdepartmental boundaries.

** Closely associated with each other with the difference being that minimizing focuses more on improving tools and technology, whereas simplifying focuses more on how workers use tools and technology.*

2.2.2 LEAN-THINKING APPLICATIONS IN CONSTRUCTION

De Solminihac et al. (1994) discuss the notion of introducing new technologies to existing construction practices. The authors analyzed the situation in Chile in four planned stages: (1) description of construction methods, (2) efficiency and quality diagnosis, (3) construction work evolution in productivity, quality, and cost curves (4) analysis of the completion and fulfillment of study objectives. The methodology was applied on a project to determine the implications of implementing such strategies. The impact of mobile warehousing, concrete plant, organizational policy changes, as well as team-oriented conduct is described by De Solminihac et al. (1994). An increase in productivity and a decrease in complaints resulted from this. Koskela and Leikas (1994) explored the benefits of lean-thinking in construction component manufacturing. Several companies were selected for this pilot study to draw up a methodology for initiating lean production activities in this domain, and to verify the potential of lean production theory in this industry through practical experiments. Participating companies in this pilot study achieved improvements such as an increase in productivity, quality, and worker participation as well as a decrease in errors related to order information and production cycle time. Hence, both lean production and information technology are seen as approaches in improvements that complement each other. Eaton (1994) offers a strategy for implementing lean productivity in increasing order of difficulty and increasing effectiveness in the following categories: (1) reflection, (2) recruiting, (3) rewarding, (4) re-orientating, and (5) restructuring. Reflection, in terms of flow and conversion improvements, advocates that what went well together with the problems incurred is necessary to provide feedback for future improvements. Recruiting the right personnel who are capable of identifying potential changes is essential. Including reward incentives to those who help implement lean productivity improvement is also significant. Restructuring occurs after re-orientating. The re-orientating of management to realize the importance of downward interrelations (management down to worker) within the hierarchy rather than the typical upwards attitude is a vital element in the implementation process. Nonetheless, the most difficult and effective means of achieving lean productivity improvements is restructuring. Identifying what is non value-adding and what is value-adding will necessitate total cooperation from everyone in the organization.

The term Just-In-Time (JIT) describes the delivery of materials to a construction site. The theory suggests that construction materials will be brought to their location for final installation and be installed immediately upon arrival without incurring any delay due to storage in a laydown or staging area. The concept, introduced by Taichi Ohno of Toyota (Howell, 1999), implemented a pull system using 'kanban' (Japanese cards) to achieve the JIT system of lean production. The method has been used in several studies dealing with structural steel supply as well as concrete delivery. Tommelein and Weissenberger (1999) believe that the application of JIT philosophy to steel erection is viable since structural steel frame erection is a major construction phase on many projects. Issues such as type and location of buffers within two steel erection construction processes (industrial and building steel construction) is explored and concluded that this is one area of construction that will lay down the foundation for further studies to take advantage of the benefits of JIT practices. Ready-mix concrete delivery is a typical example of JIT production in construction. Tommelein and Li (1999) dissect the pros and cons, particularly the variability of the contractor's demand, of the relationship between the contractor and the concrete plant. Symbols for value stream mapping and the following two cases were investigated: (1) traditional integration of batching and delivery of concrete and integration of delivery exemplifies this "pull" system through the contractor's order, except the plant decides when the concrete is available (2) placement of concrete, with the assumption that the contractor possesses its own fleet of trucks. The contractor can overcome any delivery (schedule) problems by picking up concrete from any available plant. The plant in the first case requires an advanced notice whereas the second case does not. Therefore, the crew in the second case can work at a pace without worrying about when the concrete arrives.

2.3 TIME STUDY

2.3.1 OVERVIEW

Time study is an industrial engineering performance measurement technique that is used to determine reliable time standards for a work process while accounting for fatigue, personal and unavoidable delays. The work process to be studied is broken down into definitive work elements, i.e. into work steps that have definite start and end points. The time study methodology has been around for many years and has several occurrences within the construction industry. This section reveals the instances where time study either played a significant or minor role towards the outcome of the study at hand. Several discussions depicting some of the earliest work improvement studies are presented prior to the discussion on time studies.

2.3.2 EARLY WORK IMPROVEMENT STUDIES

Graham (2003) discusses one of the earliest instances of work method improvement. In 1885, Frank Bunker Gilbreth revolutionized the bricklaying work method while working as a bricklayer for the Thomas J. Whidden Company. For a few years, Gilbreth observed each bricklayer and then gathered many of the best bricklaying methods as well as incorporating his improvement ideas such as a bricklaying scaffold. On one particular wall, he had improved the productivity by 190%, up to 350 bricks per hour from 120 bricks per hour. This early success had paved the way for his lifelong journey to find the efficient means of completing any type of task. He eventually shared his insights with his wife, Lillian, their twelve children, and industry. Gilbreth and his wife used motion picture technology to study the motions of the workers in some of their experiments.

The Internet Center for Management and Business Administration (2003) presents two philosophies of work improvement advocated by Frederick Taylor. In Taylor's book, "The Principles of Scientific Management", Taylor describes how the application of science to worker management could enhance worker productivity. He wanted to optimize the way tasks were being performed with intentions of training workers to perform their specialized sequence of motions in the most efficient manner. In his experiment for "the science of shovelling", it was determined that the optimal weight that a worker should lift in a shovel was 21 pounds. Due to the variability in the densities of the material being shovelled, he believed that a shovel should be sized in such a way that 21 pounds of material will always be shovelled. The introduction of these optimal shovels resulted in a 3 to 4 fold increase in productivity and rewards were presented to the workers accordingly.

Also, Taylor investigates the science of loading and unloading. The "pig iron" experiment presents the importance of hiring workers based on their suitability, such as physical strength, to a particular task. Taylor suggested that the average pig iron workers could move 12.5 tons per day, but could improve to around 47.5 tons per day if given direction and incentive. Analyses to determine the optimum working and resting periods for the workers were conducted in order to perform at the 47.5 tons per day as suggested. Taylor concluded that about 1/8 of those pig iron handlers, although not superior and upper-class people, they were best-suited to the pig iron job based on their physical abilities.

2.3.3 TIME STUDY APPLICATIONS IN CONSTRUCTION

Gransberg (1998) reviews five methods used to estimate haul fleet production based on optimal analysis and then compared these results to actual field observations. The first four methods mainly utilized mathematical models that ultimately establish optimum fleet size (haul units) composition. The fifth method utilizes statistics derived from industrial engineering methods (time and motion studies) to determine the optimum productivity of an existing fleet. The results of the time and motion study revealed that consistent cycle times occurred when predicting productivity. However, the results seemed on the high side; the author reasons that the method conducted did not account for lost cycles such as personal delays, and hence, an overestimation of daily production results. Proper time study would have recorded the amount and type of delays. Setting of production standards is intended to minimize delays while setting allowances for personal, fatigue, and delays.

Compared to the other four methods in this analysis, this technique seemed to be described as the best evaluation tool for projects just getting started. The comparison of various methods exposed the notion that haul fleet production estimating is a complex, highly dynamic operation and should be carefully carried out.

Salim and Bernold (1994) analyzed a rebar installation process and discuss that due to the non-existence of rebar installation placement schemes, considerable time and other resources are wasted for searching, identifying, and re-handling the needed bars for the sequential assembly operation. In order to systematically examine the crew performance of all the tasks and actions of a rebar crew, the authors used data-collection techniques that include: (1) Productivity Rating, (2) Five-Minute Rating, and (3) Continuous Time Study. For this research effort, all three of the data-collection techniques demonstrated that process planning, as for placement-oriented delivery and staging according to the need of assembly sequences, is a promising technique to achieve significant productivity increases in rebar placement. The productivity improvement was about 30% compared to the traditional method. Salim and Bernold (1994) also revealed that since reinforced-concrete structures represent a major portion of today's construction, improvements in productivity of rebar placement reduces the overall costs of such projects.

Navon (2000) describes the development of a floor-tiling robot after an analysis of the feasibility to automate on-site building construction. A field investigation that included a time study was required to thoroughly explore the manual process as well as to measure the work inputs in the manual work. The development and performance measurement of the robot were carried out with a graphic simulation system. The time study method of data-collecting as well as those measurements from the graphic simulation system helped realize that the robot's work output is expected to be 2 – 5 times higher than that of the manual work. The progress at this point of the robot development convinced the robot developers to concentrate mainly on the robot's autonomy at a workstation.

As was the case in the robot development, the use of an industrial engineering performance measurement such as a time study, was employed to assist in the development of a computer-aided system to improve production rates in construction. Christian and Hachey (1996) advocate the use of video and time studies used on past research conducted in the area of identifying the factors that may influence worker productivity on construction sites. By being able to accurately predict production rates, this can either be the breaking point of whether or not the contractor is successful in winning or losing the contract.

Hrebar (1997) describes reasoning of the applicability of using large wheel loaders as the primary loading equipment in open-pit iron-ore operations. Time studies were performed to provide indications of machine performance and utilization. That is, a projection of the maximum production capabilities of the loaders is illustrated. Hrebar (1997) summarizes the data, performs an economic analysis (total unit cost basis and present value cash flow analysis) and compares the results for both loading alternatives using either large wheel loaders or cable shovels.

The development of specialized "off the shelf" time study software and data collection for the complete shift of the workers can help resolve some issues of why early applications of using methods such as time studies were unsuccessful at the time. The study for the maintenance crews of the drainage operations sector in the City of Edmonton uses the software Timer Palm™ as an example.

2.4 GENERAL PURPOSE SIMULATION

2.4.1 OVERVIEW

Computer simulation is defined as the process of designing a mathematical-logical model of a real-world system and experimenting with the model on a computer (Hajjar and AbouRizk, 2000). However, the use of simulation in the construction industry was believed to be minimal due to the complexity and lack of knowledge of simulation methodologies.

Since the late 1950's, the Faculty of Civil Engineering-Construction in Stanford has pioneered and continued the development of three powerful analytical tools for the application in construction. After developments in low-cost microcomputers and related equipment, it has become possible to bring these three areas together using a laboratory approach. One of these three areas was "Computer-based simulation modeling for design, testing, and analysis of systems of equipment and methods for field operations". In the 1960's, the simulation language GPSS (Greenberg, 1972) was introduced. It pioneered an emphasis on a modeling methodology that conceals from the user the mechanics of the simulation. In the 1970's and 80's, several General-Purpose simulation languages like SIMSCRIPT, GPSS/H, SLAM and SIMAN, were introduced and /or modified. In construction, Halpin (1976) developed CYCLONE (CYCLic Operation NEtwork). It was the main step towards giving interests in the application of computer simulation in construction. Numerous examples of construction process models have now been developed and described in many publications since that.

Early simulation users were required to build a model by writing programming code using languages like FORTRAN, and through experimentation by directly manipulating the computer program. This was followed by the introduction of simulation specific programming environments where users write simulation specific code or access a provided function library. In the next phase of development, a host of systems were introduced that allowed for alternative model development. This meant that modellers no longer had to write code directly. Graphical modeling made it possible to define the simulation model by creating, manipulating and linking a number of available basic building blocks. This meant that users no longer had to be proficient in programming (Hajjar and AbouRizk, 2000).

Computer simulation is a proven technology and countless studies have been performed to demonstrate its applicability to the analysis of a wide range of construction operations including aggregate production, earth-moving, mining, and tunnelling. Also, its applicability to the analysis of maintenance and rehabilitation operations is a significant growing simulation application area. Although static representation of the maintenance operations are helpful in planning various aspects of a project, many of the considerations that involve efficient management of a job related to the movement of resource units around the construction process interject dynamic effect, and increase productivity which is the manager's major concern. The construction/maintenance simulation systems are ideally suited for the analysis of such systems. These systems are a valuable aid in allowing the formulation of pre-construction/maintenance scenarios by management strategies when complex construction/operations processes are encountered.

The introduction of Simphony provided the practitioner who is knowledgeable in a given domain, but not necessarily in simulation, the ability to develop a special purpose simulation (SPS) with visual modeling tools that highly resemble the real-world construction system. The services provided by Simphony as a development environment allows for developing flexible and user-friendly simulation tools in a relatively short time (AbouRizk and Mohamed, 2000). Although Simphony's intent was to provide as a medium to develop SPS tools, its strength also lies within its ability to develop general purpose simulation (GPS) tools. Minimal background in simulation, however, is required to exploit Simphony's GPS ability.

2.4.2 COMMON TEMPLATE

The common template successfully developed in Simphony combines the power of functions found in stand-alone GPS software as well as providing the developer with basic ingredients used to model a system using process interaction concepts. The ability to interact with elements from other simulation templates is useful in applying different behavioural traits to the system modeled. Table 2 briefly outlines the elements within the common template.

Table 2: Elements of the common template (AbouRizk and Mohamed, 2000)

Element	*Description*
Composite	The composite element is used to build sub-models inside the main model. The user can create other elements as children inside a composite element and link them to higher-level elements through *InPort* and *OutPort* elements.
Conditional Branching	This element enables routing entities into two different branches based on a condition associated with the element.
Probabilistic Branching	This element enables routing entities into a number of different branches based on a probability associated with each branch.
Resource Handling Elements	These are a number of elements for managing resources in the model. They allow declaring resources and waiting flies, requesting, and releasing of the declared resource. Multiple or single resource requests in addition to prioritized queuing are allowed.
Create Entities	This element creates new entities with the number, start time and time intervals specified by the user and transfer them out through its output connection point.
Set Entity Attributes	Assigns values for new or existing attributes of entities passing through it
Consolidate	The consolidate element helps managing the number of entities flowing through it by either consolidating or cloning them.
Execute	This element enables the execution of a user written code during the simulation to perform any function that is not supported by the elements in the template.
Statistics Element	A number of elements that help declaring and collecting statistics at key points in the model.
Task	This element represents a normal task that requires duration to perform.
Trace	This element enables producing trace messages at selected points to check the integrity of the model.

2.4.3 CYCLONE

The second GPS template found in Simphony enables the user to develop simulation models based on Halpin's CYCLONE (CYClic Operations NEtwork) technology. Using a set of graphical elements, the CYCLONE format is used to model construction situations by considering the repetitive activities of the job site and the cyclic movement of the production system (Appleton, 2002). In addition to elements for supporting hierarchical modeling and probabilistic branching, the standard CYCLONE elements (i.e. queue, normal, combi, generate/consolidate) are supported. "The hierarchical feature in the templates allows embedding CYCLONE models in other models created by different templates."(AbouRizk and Mohamed, 2000)

2.5 CONCLUSIONS

This chapter discusses the fundamentals of Ohno's lean principles, work performance measurement using time study, and general purpose simulation. Ohno's beliefs proved to be a successful means of improving work as evident in the ready-mix concrete delivery example. Work improvement has had early applications such as Gilbreth's bricklaying techniques and Taylor's shovelling experiments. That led to the collaboration of time study in various aspects in the construction industry such as in the optimization of the process of rebar installation. Simphony's strength lies within its ability to produce both special and general purpose simulation models created by novice and expert users alike. The development of Simphony has provided those in the construction community a means of playing out alternative scenarios without having to test them out in the field. The Drainage Operations Branch in the City of Edmonton has benefited from this methodology with the low pressure flushing activity. During the early stages of the Work Analysis Study, some experimentation was done with models on the crews (other than the low pressure flushing, LPF, pilot crews) to see how much productivity improvements could be made. Given the constraints at the time, it was decided by Drainage Operations management to not implement them. The research presented in the thesis builds on the success of the pilot study conducted on the LPF crews. Additional scenarios to improve crew productivities will be presented other than those previously investigated. Appendix A also contains additional recommendations for future studies to be initiated by Drainage Operations management.

CHAPTER 3: CURRENT INDUSTRIAL ENGINEERING PERFORMANCE MEASUREMENT METHODOLOGY

3.1 OVERVIEW

Work performance measurement is a methodology, which has been around for many years and employed by industrial engineers to examine work productivity. Developing methods of performance improvement encompasses several activities, including Work Measurement and Work Simplification. This research adapted the Work Analysis Study for the performance measurement to assess and improve the productivity of the City's drainage maintenance operations.

3.2 WORK MEASUREMENT

Work Measurement (WM) is the application of techniques designed to establish standard times for a qualified worker to carry out a specified job at a defined level of performance (Matias, 2001). There are four methods of work measurement available: pre-determined time standards (PTS), standard data, time study, and work sampling. All of these techniques are based on facts and consider each detail of work. The normal time required to perform the entire work cycles are determined when using the first three procedures whereas in work sampling, the objective is to investigate proportions of total time devoted to the various activities that constitute a job or work situation. Table 3 describes the advantages and disadvantages in choosing these techniques to perform the work measurement. The most widely used method is the time study due to its simplicity and relatively low learning curve for those new to the methodology. Methods for collecting time data for the time study have not changed theoretically, only technologically. Traditionally, the use of a stopwatch and a pad of paper were the norm. The introduction of data collection software for the personal computer (PC), such as Timer Palm™ which was used in this study, has made summarization of time study data attainable within a matter of seconds. It normally takes hours to setup and perform the numerous calculations without the aid of a PC.

There are two different types of work elements that are measured: (1) operation – time recorded on a time study which is spent on those work elements for which the study is to be summarized and (2) foreign elements – time recorded on a time study which is spent on work other than the operation work elements. Table 4 provides a description of these two types of foreign elements. There are two types of foreign elements: (1) Non-productive Elements – delays or lost time consisting of idle time (IT), Excessive Work (EW), Personal Time (PT), and Instruction (I) and (2) Productive elements – necessary delays not related to the operation being studied consisting of either Productive Interruption (PI), and/or Unrelated Work (UW).

Table 3: Comparison of different work measurement techniques (Matias, 2001)

Time Study	*Predetermined Time Standards*	*Standard Data*	*Work Sampling*
Advantages			
1. Enables analysts to observe the complete cycle, providing an opportunity to suggest and initiate improvement. 2. The only method that actually measures and records the actual time taken by an operator. 3. More likely to provide coverage to those elements that occur less than one per cycle. 4. Quickly provides accurate values for machine-controlled elements. 5. Relatively simple to learn and explain.	1. Forces detailed and accurate descriptions of the workplace layout; motion patterns; and shape, size, and fit of components and tools. 2. Encourages work simplification to reduce standard times. 3. Eliminates performance rating. 4. Permits establishing methods and standards in advance of actual production. 5. Permits easy and accurate adjustments of time standards to accommodate minor changes in method. 6. Provides more consistent standards.	1. Averages performance rating. 2. Establishes consistent standards. 3. Permits establishing methods and standards in advance of actual production. 4. Allows standards to be established rapidly and inexpensively. 5. Permits easy adjustment of time standards to accommodate minor changes in method.	1. Eliminates tension caused by constant observation of the worker. 2. Does not require continuous observations over a long period of time. 3. Represents typical or average conditions over a period of time where conditions change from hour to hour or day to day. 4. Permits simultaneous development of standards from different operations. 5. Ideally suited to studies of machine utilization, activity analyses, and delays. 6. Can be used with performance rating to determine standard times.
Disadvantages			
1. Requires the performance rating of a worker's skill and effort. 2. Requires continuous observation of the worker over repeated work cycles. 3. May not provide accurate evaluation of non-cyclic elements. 4. Requires work to be performed by an operator.	1. Depends on complete and accurate descriptions of the required methods for the accuracy of the time standard. 2. Requires more time for the training of competent analysts. 3. More difficult to explain to workers and supervisors. 4. May require more work-hours to establish standards for long-cycle operations. 5. Must use stopwatch or standard data for process-controlled and machine-controlled elements.	1. Involves significant costs in setting up the standard data. Once these costs are incurred, additional costs are needed to maintain the system. 2. May not accommodate small variations in method. 3. May require more skilled analysts for complex formulas. 4. More difficult to explain to workers and supervisors. 5. May result to significant inaccuracies if extended beyond the scope of the data used in their development.	1. Assumes that the worker uses an acceptable and standard method. 2. Requires that the observer to identify and classify a wide range of work activities and delays. 3. Should be confined to constant populations. 4. Makes it more difficult to apply a correct performance rating factor than a time study.

Table 4: Foreign elements description (Sparks, 1973)

Code	Description	Explanation
IT	Idle Time	Employee is not working, either when work is available or not available.
EW	Excessive Work	Time spent on superfluous work or trips. Also time spent on unnecessary checking or reviewing or redoing an operation due to mistake of the worker or organization being studied (rework)
I	Instruction	Time spent giving or receiving instruction, other than explanation of assignment
PT	Personal Time	Time spent attending to personal needs, trips to restroom and water fountain, lighting cigarette, etc.
PT*	PT, Coffee Break	Authorized rest periods.
PI	Productive Interruption	Time spent on short, necessary delays not related to operations being studied such as answering questions, telephone calls, radio calls, receiving task instructions (explanations) from immediate supervisor, etc. Also, short amounts of time spent on making minor adjustments to equipment and accessories.
UW	Unrelated Work	Time spent on productive work for which standards are not to be established, or for work where sufficient samples have already been studied and occurs while other work is under study.
AI	Analyst Interruption	Time spent answering analyst's questions, making counts for the analysts, etc.
L	Lunch Period	Time spent on authorized lunch period. Extended lunch period beyond the authorized time would normally be classified as personal time.

3.3 WORK SIMPLIFICATION

Work Simplification is a means of sub-dividing processes into activities and tasks, and sub-dividing activities and tasks into process steps (work elements), which are classified and identified as either value-added or non-value-added. Establishing the framework of what work steps are value-added or non-value-added is the key to work simplification. Value-added (VA) process steps refer to either operation steps or combined operation and inspection steps for which the basic work performed is of value to the customer and advances the process. An example of a VA process step is "Open Manhole". During the maintenance process Cleaning Mains by High Pressure Flushing, in order to advance the process, the hose must be inserted into the sewer mainline, thus justifying that "Open Manhole" is a value-added work step. Non value-added (NVA) process steps refer to those steps that are neither an operation step nor a combined operation and inspection step. Examples of work elements that do not bring value to the customer are handling, transportation, delay, inspection, storage, and rework steps. Table 5 summarizes the basic process steps used in work simplification. By utilizing these symbols, the NVA tasks of a process can be easily identified visually. Work simplification can also be synonymously expressed with lean construction, work design, methods engineering, and methods study. In evaluating the efficiency of work methods during the 1999 Efficiency Audit (Roesch, 2000), a minimum reasonable split between VA and NVA tasks of 50/50 was used. Ideally at this level (task or work step) a ratio of 80:20 should exist to minimize the amount of NVA steps in the entire business process. Typically for most business or industrial processes, if the NVA steps are not minimized at the task (or work step) level, 90 to 98 % of the entire business process will end up being non-value added. The entire business process can refer to the Drainage Operations section, which is a business unit. The business process of the business unit (Drainage Operations) includes the core business process composed of all maintenance activities and secondary processes composed of administrative activities. When all the VA and NVA time is added up for the activities of the core process and the activities of secondary processes, the business unit's overall business process will be 90 to 98% non-value added. However, in this study, any improvement in the overall productivity of the crew is acceptable and demonstrates progress in the right direction. An advantage to using work simplification is that the sample does not have to be statistically-based. That is, only the work method and how to improve it is the primary concern.

Table 5: Basic process step symbols and descriptions

Symbol	Process Type	Description	VA/NVA
▣ ●	Operation	Any value-adding step. Directly moves a process forward. (O/I & O)	VA
➤	Handling	Loading and unloading objects, equipment, and accessories. Making adjustments to equipment and accessories.	NVA
→	Transportation	Any action that moves something, including objects, people, and information.	NVA
■	Inspection	Includes quality and quantity inspections, reviews, and authorizations.	NVA
◗	Delay	Unscheduled delays of materials, parts, products, or people.	NVA
▼	Storage	Scheduled delay of materials, parts, or products.	NVA
Ⓡ	Rework	Any unnecessarily repeated operation step.	NVA

3.4 TIME STUDY

The predominant method of work measurement is the Time Study. "Time study is a technique of establishing an allowed time standard for performing a given task, based upon measurement of the work content of the prescribed method, with due allowance for fatigue and or personal and unavoidable delays" (Niebel, 1982). The objective of a time study is to establish reliable standards for direct and indirect work performed for the efficient and effective management of the operation. With reliable time standards, work can be scheduled as to maximize output over time, thus obtaining high utilization of both labour and equipment, and ultimately, the assurance of the maintenance of quality requirements. Management is then able to investigate the differences between actual and standard times and take appropriate action where necessary. Moreover, the resulting productivity standards usually facilitate the need to either revise or modify the work process by means of methods engineering. Since time is a common measure for all jobs, the time standards can be used as a basis for comparing various methods to do the various drainage operations maintenance work processes in this study. The terms methods improvement, methods engineering, operations analysis, and work simplification have been used synonymously in industrial engineering literature (Kachhal, 2001). However, the study utilizes the principles from lean construction (or lean thinking) as its focal point since these principles are fundamentally parallel in theory.

3.4.1 EFFECTIVE TIME STUDY

Several fundamental requirements must be met before a time study can be performed. The analysis of the work involving the employees "being clocked" is often misunderstood by the workers and almost immediately rejected. Beforehand, the workers to be studied have to be thoroughly notified and acquainted with the objectives of the time study in order to minimize the amount of hostility between those involved in the work measurement program. The significance of this work measurement procedure requires an analyst that can handle the responsibility of administering the time study while maintaining good relations between all parties. The analyst should regularly meet the following requirements (Niebel, 1982):

1. To study the existing method carefully before conducting the time study to ensure that the method is correct.
2. To review with the foreman all aspects of the operation in order to obtain his or her endorsement of the tooling, materials, and procedure being utilized by the operator.
3. To respond to any questions posed by the operator, labourer, or the foreman regarding the time study procedure.
4. To record on the time study form all details of the method under study.
5. To record accurately an adequate sample of element times in order to allow the development of an equitable standard.
6. To evaluate the performance of the operator honestly and fairly.
7. To apply an appropriate allowance to all normal times where applicable.
8. To calculate accurately the standard times for each element of the time study.
9. To conduct one's self in such a manner that one will obtain and hold the respect and confidence of the representatives of both labour and management.

It is desirable to determine, before the start of the study, the elements into which the operation is to be divided. Breaking the operation into work elements that have easily identifiable start and end points may also require the analyst to view several cycles of the operation to ensure that the elements are consistent throughout the cycle. Elemental divisions of about 0.04 minutes are about as fine as can be read consistently by the experienced time study analyst (Niebel, 1982).

3.4.2 PERFORMANCE RATING

Rating the performance of each worker is very significant when conducting the time study since the analyst is essentially timing each individual and not everyone works at the exact same pace or level. "The purpose of performance rating is to determine, from the time actually taken by the operator being observed, the standard time that can be maintained by the average qualified worker and that can be used as a realistic basis for planning, control, and incentive plans" (Matias, 2001). To ascertain the notion of the worker being rated fairly, the analyst must receive the proper and comprehensive training as well as become familiarized with the sequence of the work steps. This will enable the analyst to have a clearer understanding of what performance rating is considered as standard or normal (100 % level of effort). Typically, the normal time required to complete a job is usually indicated by observing the smooth workflow between work steps and the comfortable speed of the individual carrying out the work. Depending on the skill and effort of the worker, it may be necessary to adjust upwards to 'normal' the time of an above-average worker and adjust downwards to 'normal' the time of a below-average worker. The performance rating adjusts the observed time *(OT)* for each work element performed during the study to the normal time *(NT)* from the following equation:

$$NT = (OT)\left(\frac{R}{100}\right)$$

where R is expressed as a percentage (rating). For instance, if the analyst decides that the work step being observed is being performed at a slower pace than the conceptual normal pace, it is applicable to use a factor less than 100 such as 85 or 90. On the other hand, if the observed work step is decided by the analyst to be faster than the conceptual normal pace, a factor greater than 100 such as 105 or 110 can be used. Unfortunately, neither a universally accepted method of rating the performance nor a universal concept of normal performance exists. There are, however, several rating systems available, but are generally dependent on the subjective decision by the analyst. This is the primary reason why the analyst must undertake some instruction and preparation before conducting the study. Generally, the rating system that is selected is one that the analyst finds easiest to understand, apply, and explain. Table 6 summarizes the performance rating systems available.

Table 6: Performance rating systems (Salvendy, 2001)

Rating System	Description
Westinghouse System (Westinghouse Electric Corporation)	1. It is one of the oldest rating systems. Considers four factors in evaluating performance: skill, effort, environmental condition, and consistency. 2. Newer version called Performance Rating Plan. In addition to using the operator-related physical attributes, they attempted to evaluate the relationship between those physical attributes and the basic divisions of work.
Synthetic Rating (Morrow)	Eliminates judgement from time study analyst to gain consistency. Determines performance factor for representative effort elements of the work cycle by comparing actual elemental observed times and fundamental motion data. $P = \frac{\text{fundamental motion time}}{\text{observed mean element time}}$
Speed Rating	Most widely used system. Considers rate of accomplishment of the work per unit of time. 100% is normal, 125% is 25% faster than normal, and 90% is 10% slower than normal.
Objective Rating (Mundel and Danner)	Evaluates performance using six categories. It is a system which requires multiplying the employee's speed by the difficulty of the activity. Factors influencing the difficulty adjustment that have been assigned numerical values for a range of degrees are: (1) amount of body used, (2) food pedals, (3) bimanualness, (4) eye-hand coordination, (5) handling requirements, and (6) weight handled or resistance encountered. $N = PDT$ where N = computed normal time for element P = pace rating factor D = difficulty adjustment factor T = mean observed elemental time

3.4.3 ALLOWANCES

"Allowances are provided to cover time taken for personal needs, unavoidable delays, and a general slowdown of performance because of fatigue" (Niebel, 1982). Only a certain number of allowance factors will apply depending on what work element is considered. The allowance is characteristically expressed as a percentage to be used as a multiplier in the equation that adjusts the normal time (NT) to the standard time (ST):

$$ST = NT + NT(allowance) = NT(1 + allowance)$$

The total allowance is then determined by summation of the individual allowances (percentages). Table 7 displays the values the International Labour Office has developed for allowances. These values are subsequently used during the analysis of the time study data (see Section 3.5.7 and Figure 9 for details).

Table 7: Effects of working conditions on determining allowances (Niebel, 1982)

Allowance	*Value (%)*
Constant Allowances	
Personal allowance	5
Basic fatigue allowance	4
Variable Allowances	
Standing allowance	2
Abnormal position allowance	
Slightly awkward	0
Awkward (bending)	2
Very awkward (lying, stretching)	7
Use of force or muscular energy (lifting, pulling, or pushing) – weight lifted, in pounds:	
5	0
10	1
15	2
20	3
25	4
30	5
35	7
40	9
45	11
50	13
60	17
70	22
Bad light	
Slightly below recommended	0
Well below	2
Quite inadequate	5
Atmospheric conditions (heat and humidity) – variable	0 – 10
Close attention	
Fairly fine work	0
Fine or exacting	2
Very fine or very exacting	5
Noise level	
Continuous	0
Intermittent – loud	2
Intermittent – very loud	5
High-pitched – loud	5
Mental strain	
Fairly complex process	1
Complex or wide span of attention	4
Very complex	8
Monotony	
Low	0
Medium	1
High	4
Tediousness	
Rather tedious	0
Tedious	2
Very tedious	5

3.4.4 ERGONOMIC TIME STUDY

The conventional time study can be applied from a perspective with a different goal in mind; this is called the Ergonomic Time Study. This type of analysis was performed on all of the crews in the study. The same principles apply in terms of conducting the time study, i.e. using a device that measures the amount of time a work element is completed. In addition, a video camera can assist the observer in conducting the ergonomics study by allowing him or herself to view the workers at a comfortable pace. The analyst can stop and rewind the video at anytime to increase the integrity and accuracy of the analysis. Completing the ergonomic time study involves breaking the whole process into: the movements of particular muscle groups (or body parts), the positions (such as kneeling, standing, walking, stooping, etc.), motions (such as pushing/pulling or lifting/lowering), and senses used by the worker of interest. "Ergonomic time studies can be used to determine if an individual is working at an output level that will potentially cause premature long-term physical deterioration" (Ousnamer, 2000). Moreover, these studies can assist in determining work levels that will cause severe fatigue. Ergonomic time studies help management determine if the worker performing the activity is performing at a safe muscular respiration level. The output of an ergonomic time study is the work/rest ratio. This ratio indicates the amount of time the particular muscle group is working compared to the amount of time the muscle group is relaxed. Normally, a ratio of 50/50 is an acceptable target. The results of the ergonomic time studies are the physical demands analyses as described in the following section.

3.4.5 PHYSICAL DEMANDS ANALYSIS

Another by-product of the time study is the Physical Demands Analysis (PDA). The PDA is completed by using the results from the time study and ergonomics analysis. The results are organized in a manner that explicitly illustrates the physical requirements of the job such as the aerobic work load in METS (metabolic equivalents). One MET is the rate of oxygen utilization at rest (equivalent to 1 MET = 3.5 mL of O_2/kg body weight/min) required accounting for environmental conditions affecting the job, safety measures, lifting requirements, etc. Table 8 is a summary of the aerobic intensity required to perform the drainage operations maintenance jobs. The complete PDA summaries can be viewed in a report to the City of Edmonton's Drainage Operations Branch.

Table 8: Summary of aerobic exertion required by crew and job title (Agbulos et al, 2003)

CREW	*JOB TITLE*	*AEROBIC INTENSITY (in METS – METabolic equivalentS)*
CBC	Equipment Operator III	Light Effort, 2 to 3 METS
CBC	Labourer I/II	Moderate Effort, 3 to 5 METS
MTV	Foreman I	Light (2 – 3 METS) to Moderate Effort (3 – 5 METS)
MTV	Labourer II	Moderate (3 – 5 METS) to Heavy Effort (5 – 8 METS)
MTV	Equipment Operator III	Light Effort, 2 to 3 METS
LPF	Labourer I	Moderate Effort, 3 to 5 METS
LPF	Labourer II	Moderate Effort, 3 to 5 METS
LPF	Foreman I	Light Effort, 2 to 3 METS
CEI	Industrial Waste Inspector	Light Effort, 2 to 3 METS
HPF	Equipment Operator III	Light Effort, 2 to 3 METS
HPF	Labourer I/II	Moderate Effort, 3 to 5 METS

3.5 DATA COLLECTION

Years before computers became a predominant means of processing data practitioners prepared and analyzed data manually with a pen or pencil and pad of paper. The development of specialized work measurement software offers an efficient and very effective technique to industrial engineers. The degree of ease and relatively short analysis time for the data was convincing enough to gain acceptance within the industrial engineering community. As exemplified by lean concepts (or work simplification), each aforementioned drainage operations maintenance activity was sub-divided into work elements that possessed definite start and terminal points. These elements, such as 'Get Instructions', provide the observer with a very specific breakdown of the activity and the order in which the tasks are to be accomplished. The analyst records time data with a personal digital assistant (PDA) installed with specialized time study software. Careful consideration must be taken since the possibility of elements occurring simultaneously presents a challenge to the analyst. In cases where this arises, the observer must alternate between the two overlapping work steps. Table 10 displays the typical breakdown of the work process for scheduled mechanical cleaning of catch basins. The activity is broken down into tasks and is further sub-divided into work elements (or work steps).

3.5.1 DATA COLLECTION SCHEDULE

The data collection portion of the study consumed the greatest amount of time to accomplish. There are two types of data collected: (1) Non-statistical – standards developed are not based on a confidence level and precision, and (2) Statistical – standards developed are based on a confidence level and precision. Initially, non-statistically based engineered productivity standards were developed through work measurement and work simplification (lean-thinking) analysis for the 1999 Efficiency Audit. Over a period of approximately 3 months, the work crews for the statistically-based productivity standards were observed on a daily basis. It was decided by the parties involved that data collection was to occur during weekdays and at a convenient time for the analyst. The three-month period includes the videotaping of the work activities on a daily basis for one week for the ergonomic data collection and physical demands analyses. Table 9 is a breakdown of the crews that the Office of the City Auditor deliberated along with the number of days of observation for both statistically and non-statistically based data. Given s (standard deviation), t (determined from percentage points of **t** distribution based on sample size, n, and probability, p), and k (percentage of the mean, μ, the OCA calculated the number of cycles to observe the crews for the statistically-based productivity standards using the following equation from Matias (2001):

$$N = \left(\frac{st}{k\mu} \right)^2$$

The actual number of observation days was determined by dividing the number of cycles (observations) calculated divided by the frequency of occurrence of the core element for each crew

(CEI-inspection step, CBC-vacuum step, MTV-televising step, HPF-flushing step, SLR-rodding/televising steps) per day. This number was calculated from the non-statistical sample for work simplification conducted during the efficiency audit.

Table 9: Crew observations

CREW	*# DAYS OBSERVED*
WORK MEASUREMENT (Statistical)	
Commercial Establishment Investigation	5
Service Line Rodding/Televising	27
Catch Basin Cleaning	10
High Pressure Flushing	147*
Mainline Televising	15**
WORK SIMPLIFICATION (Non-Statistical)	
Commercial Establishment Investigation	4
Service Line Rodding/Televising	4
Catch Basin Cleaning	3
High Pressure Flushing	4
Mainline Televising	5
1999 EFFICIENCY AUDIT (Non-Statistical)	
Commercial Establishment Investigation	1
Service Line Rodding/Televising	2
Catch Basin Cleaning	N/A
High Pressure Flushing	3
Mainline Televising	2

**Used tracking spreadsheets (calculated value was 61 observation days – not enough resources)*
***2 of these days were omitted in data analysis due to work not inspecting mains by televising*

Table 10: Typical table describing work elements (Catch Basin Cleaning shown)

1) WORK PREPARATION
- Get Instructions
- Vehicle Check

2) CATCH BASIN CLEANING
- Park Truck & Traffic Control
- Assemble Vacuum Pipe
- Open CB
- Mark CB
- Lower Vac into CB
- Vacuum Debris
- Use Stick Puller
- Wash CB/Vacuum
- Raise Vac Pipe
- Disassemble Vac Pipe
- Close CB
- Load Traffic Cones
- Move to next CB
- Move to next MH
- Open MH
- Dump Debris Water
- Close MH
- Dump Debris in Yard
- Move to Garage/Hydrant
- Couple Hose/Tank
- Open Valve/Fill Tank

3) WORK COMPLETION
- Clean Equipment
- Inspect Equipment
- Store Equipment
- Paper Work
- Submit Forms

4) TRAVEL/REFUEL
- Travel to 1st Site
- Travel to Next Site
- Travel to Yard
- Travel to Gas Station
- Travel to Other (store, etc.)
- Refuel

3.5.2 SOFTWARE SELECTION

As identified in Chapter 3.4, the time study was the chosen method of collecting data for the Work Analysis Study. After consulting with City of Edmonton Drainage Operations Management, Office of the City Auditor, and the University of Alberta's Construction Engineering and Management Group, it was agreed upon that the simplicity of the time study methodology and repetitiveness of the chosen maintenance work processes provided the easiest means of conducting a data-gathering scheme. The availability of the university to provide students for the data collection component of the work analysis study further validated the decision.

3.5.3 DATA MANIPULATION

Processing the data incorporated manipulation between the personal data assistant (PDA) and the notebook computer. Preceding field data collection, the work steps of each of the maintenance work activities must be entered into the PDA as prescribed in the work performance measurement chapter, based on the time study as per the number of observations summarized in Table 9. The following section provides details for analyzing the time study data and data manipulations.

3.5.4 DATA ANALYSIS – DETERMINING PRODUCTIVITY

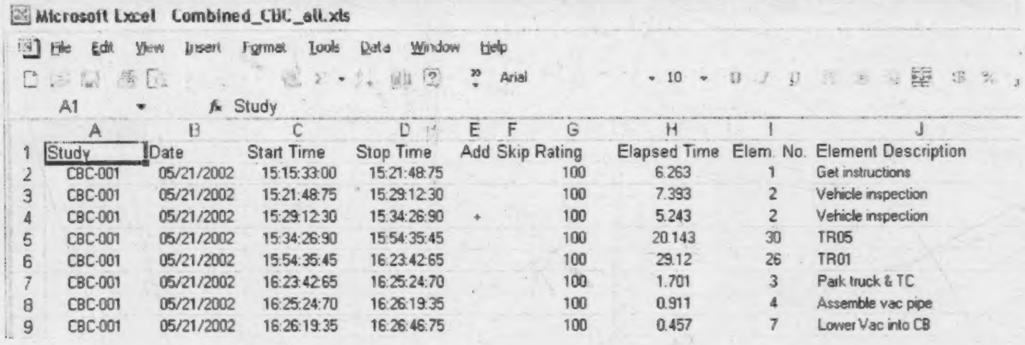
The outputs of the Timer Palm™ software are represented in Microsoft Excel™ spreadsheets, which are customized to provide specific requirements such as productivity. The productivities and accomplishments are represented in either locations or sites per day or meters per day as listed in Table 11. This section will review the process of calculating the productivity for one of the work crews, catch basin cleaning. Similarly, all the other crews have their productivities evaluated in the same manner. The standards are set in either man-hours per unit or units per man-hour, but are expressed in units (locations or metres) per day for simplicity.

Table 11: Units of measure for maintenance activity productivity

CREW	*UNITS*	
	simplistic	***standard***
Commercial Establishment Investigation	locations/day	locations/man-hour or man-hours/location
Service Line Rodding/Televising*	locations/day	locations/man-hour or man-hours/location
Catch Basin Cleaning	locations/day	locations/man-hour or man-hours/location
Low Pressure Flushing**	metres/day	metres/man-hour or man-hours/metre
High Pressure Flushing	metres/day	metres/man-hour or man-hours/metre
Mainline Televising	metres/day	metres/man-hour or man-hours/metre

**based on a 10-hr day as of 2000*
***previously established standard as pilot study in 2001*

The Excel® workbook provided with the system contains macros that perform the standard time study processing. These macros can be altered or have additional processing functions incorporated with the other worksheets provided. Once the data has been transferred from the PDA to the computer, it is automatically stored in the worksheet labelled 'Raw Data', similar to that shown in Figure 4.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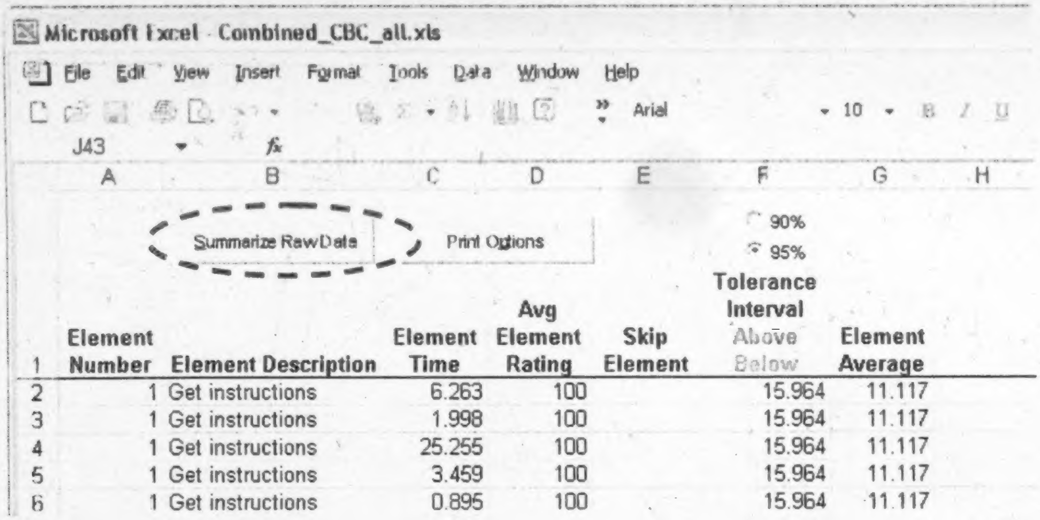
10
A1
Study

	A	B	C	D	E	F	G	H	I	J
1	Study	Date	Start Time	Stop Time	Add	Skip	Rating	Elapsed Time	Elem. No.	Element Description
2	CBC-001	05/21/2002	15:15:33:00	15:21:48:75			100	6.263	1	Get instructions
3	CBC-001	05/21/2002	15:21:48:75	15:29:12:30			100	7.393	2	Vehicle inspection
4	CBC-001	05/21/2002	15:29:12:30	15:34:26:90	+		100	5.243	2	Vehicle inspection
5	CBC-001	05/21/2002	15:34:26:90	15:54:35:45			100	20.143	30	TR05
6	CBC-001	05/21/2002	15:54:35:45	16:23:42:65			100	29.12	26	TR01
7	CBC-001	05/21/2002	16:23:42:65	16:25:24:70			100	1.701	3	Park truck & TC
8	CBC-001	05/21/2002	16:25:24:70	16:26:19:35			100	0.911	4	Assemble vac pipe
9	CBC-001	05/21/2002	16:26:19:35	16:26:46:75			100	0.457	7	Lower Vac into CB

Figure 4: Raw Data worksheet example

This worksheet (see Figure 4) displays all recorded elements including those modified by either adding (denoted by a "+" under the 'Add' column) or skipping (denoted by an "S" under the 'Skip' column). The adding feature is included to eliminate the impact of prematurely ending a work step: however the worker being timed has not completed that work step. This combines the times of the element's previous time with the "added" time without counting the "additional" time as another observation. The skipping feature provides flexibility during those times when the user accidentally selects a wrong work step. The default performance rating is 100% for each study. During the field data collection, if the analyst felt that the worker was not performing at a normal pace of 100%, the worksheet displays this in separate column (column G) for possible adjustment. The elapsed time, number, and description for an element are also transferred. Summarized data is then stored in the worksheet called 'Compiled Data'. Selecting the option 'Summarize Raw Data', all time study data as in this example for catch basin cleaning, is summarized as shown in Figure 5.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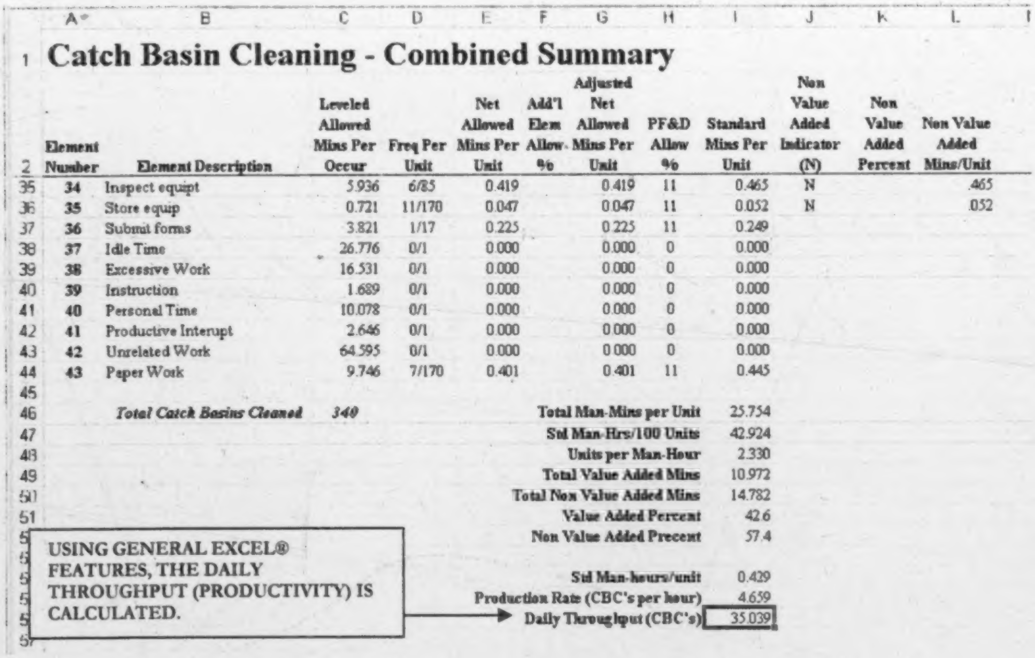
fx
A B C D E F G H
Summarize Raw Data
Print Options
○ 90%
● 95%

	Element Number	Element Description	Element Time	Avg Element Rating	Skip Element	Tolerance Interval Above Below	Element Average
2	1	Get instructions	6.263	100		15.964	11.117
3	1	Get instructions	1.998	100		15.964	11.117
4	1	Get instructions	25.255	100		15.964	11.117
5	1	Get instructions	3.459	100		15.964	11.117
6	1	Get instructions	0.895	100		15.964	11.117

Figure 5: Data is processed after pushing "Summarize Raw Data" button



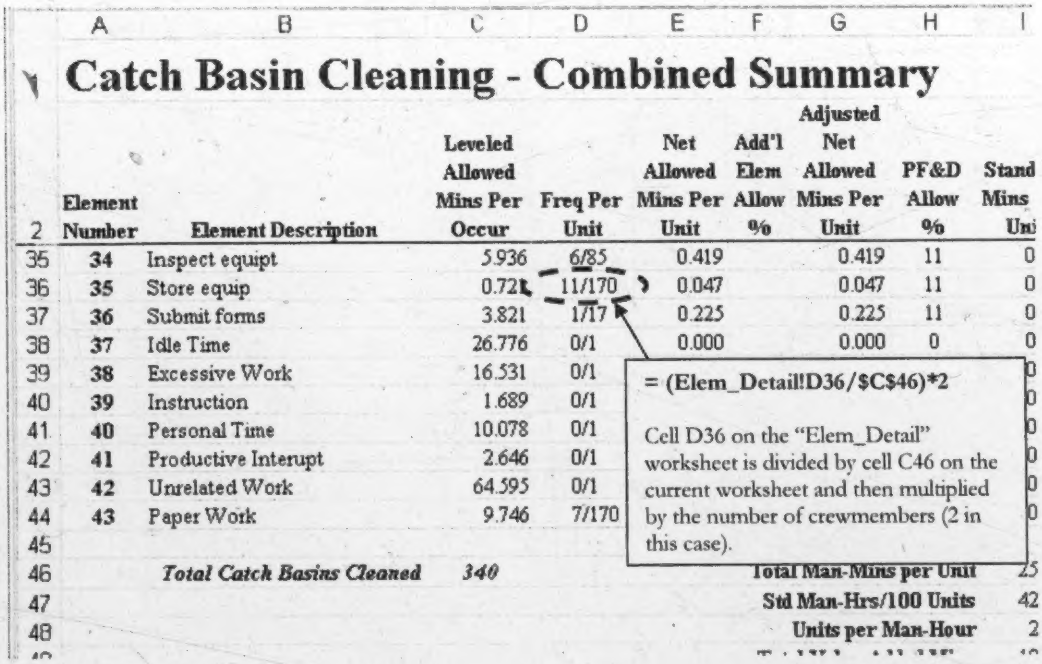
Catch Basin Cleaning - Combined Summary

	Element Number	Element Description	Leveled Allowed Mins Per Occur	Freq Per Unit	Net Allowed Mins Per Unit	Add'l Elem Allow %	Adjusted Net Allowed Mins Per Unit	PF&D Allow %	Standard Mins Per Unit	Non Value Added Indicator (N)	Non Value Added Percent	Non Value Added Mins/Unit
35	34	Inspect equipt	5.936	6/85	0.419		0.419	11	0.465	N		.465
36	35	Store equip	0.721	11/170	0.047		0.047	11	0.052	N		.052
37	36	Submit forms	3.821	1/17	0.225		0.225	11	0.249			
38	37	Idle Time	26.776	0/1	0.000		0.000	0	0.000			
39	38	Excessive Work	16.531	0/1	0.000		0.000	0	0.000			
40	39	Instruction	1.689	0/1	0.000		0.000	0	0.000			
41	40	Personal Time	10.078	0/1	0.000		0.000	0	0.000			
42	41	Productive Interupt	2.646	0/1	0.000		0.000	0	0.000			
43	42	Unrelated Work	64.595	0/1	0.000		0.000	0	0.000			
44	43	Paper Work	9.746	7/170	0.401		0.401	11	0.445			
45												
46		*Total Catch Basins Cleaned*	*340*					Total Man-Mins per Unit	25.754			
47								Std Man-Hrs/100 Units	42.924			
48								Units per Man-Hour	2.330			
49								Total Value Added Mins	10.972			
50								Total Non Value Added Mins	14.782			
51								Value Added Percent	42.6			
								Non Value Added Precent	57.4			
								Std Man-hours/unit	0.429			
								Production Rate (CBC's per hour)	4.659			
								Daily Througlput (CBC's)	35.039			

USING GENERAL EXCEL® FEATURES, THE DAILY THROUGHPUT (PRODUCTIVITY) IS CALCULATED.

Figure 6: Example of "Summary" worksheet for catch basin cleaning

The productivity for the crew was calculated to be 35.039 or 35 locations (catch basins) per day (8-hr shift). In order to compute the daily throughput, the total number of catch basins cleaned by all of the workers had to be determined. During the time period when this crew was observed, copies of each of the operator's timesheets had to be reviewed to determine their total number of accomplishments, i.e. total number of catch basins cleaned, total number of metres flushed or televised, total number of locations rodded, or total number of commercial establishments investigated. In this example, the catch basin cleaning crews' accomplishments, recorded as the number of catch basins cleaned, summed up to 340 locations. The number of observations for each element (from the 'Elem_Detail' worksheet) is divided by this number (340) and multiplied by the number of crewmembers (1 operator + 1 labourer = 2) to calculate the frequency per unit for that element. Again, this is done for each element row on the spreadsheet, as illustrated in Figure 7.



Catch Basin Cleaning - Combined Summary

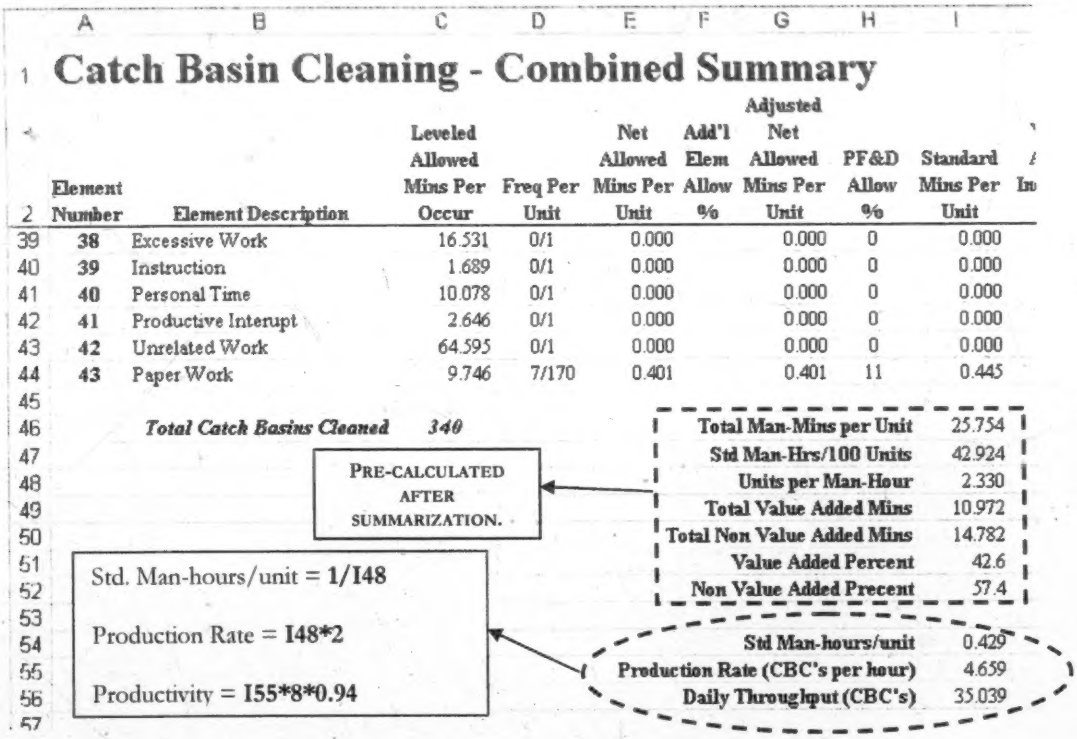
	A	B	C	D	E	F	G	H	I
2	**Element Number**	**Element Description**	**Leveled Allowed Mins Per Occur**	**Freq Per Unit**	**Net Allowed Mins Per Unit**	**Add'l Elem Allow %**	**Adjusted Net Allowed Mins Per Unit**	**PF&D Allow %**	**Stand Mins Uni**
35	**34**	Inspect equipt	5.936	6/85	0.419		0.419	11	0
36	**35**	Store equip	0.72	11/170	0.047		0.047	11	0
37	**36**	Submit forms	3.821	1/17	0.225		0.225	11	0
38	**37**	Idle Time	26.776	0/1	0.000		0.000	0	0
39	**38**	Excessive Work	16.531	0/1					0
40	**39**	Instruction	1.689	0/1					0
41	**40**	Personal Time	10.078	0/1					0
42	**41**	Productive Interupt	2.646	0/1					0
43	**42**	Unrelated Work	64.595	0/1					0
44	**43**	Paper Work	9.746	7/170					0
45									
46		***Total Catch Basins Cleaned***	***340***					**Total Man-Mins per Unit**	25
47								**Std Man-Hrs/100 Units**	42
48								**Units per Man-Hour**	2

= (Elem_Detail!D36/$C$46)*2

Cell D36 on the "Elem_Detail" worksheet is divided by cell C46 on the current worksheet and then multiplied by the number of crewmembers (2 in this case).

Figure 7: Example of calculating Frequency Per Unit on spreadsheet

The standard man-hours per unit, production rate, and productivity (daily throughput) are computed by manually entering the required formulas. Figure 8 summarizes these additional calculations. The personal, fatigue, and delay allowances are also added to the column named 'PF&D Allow'. By referring to Table 7 in Chapter 3.4, each element is determined by adding those allowances.



Catch Basin Cleaning - Combined Summary

	A	B	C	D	E	F	G	H	I
2	Element Number	Element Description	Leveled Allowed Mins Per Occur	Freq Per Unit	Net Allowed Mins Per Unit	Add'l Elem Allow %	Adjusted Net Allowed Mins Per Unit	PF&D Allow %	Standard Mins Per Unit
39	38	Excessive Work	16.531	0/1	0.000		0.000	0	0.000
40	39	Instruction	1.689	0/1	0.000		0.000	0	0.000
41	40	Personal Time	10.078	0/1	0.000		0.000	0	0.000
42	41	Productive Interupt	2.646	0/1	0.000		0.000	0	0.000
43	42	Unrelated Work	64.595	0/1	0.000		0.000	0	0.000
44	43	Paper Work	9.746	7/170	0.401		0.401	11	0.445
45									
46		*Total Catch Basins Cleaned*	*340*						

Total Man-Mins per Unit	25.754
Std Man-Hrs/100 Units	42.924
Units per Man-Hour	2.330
Total Value Added Mins	10.972
Total Non Value Added Mins	14.782
Value Added Percent	42.6
Non Value Added Precent	57.4

PRE-CALCULATED AFTER SUMMARIZATION.

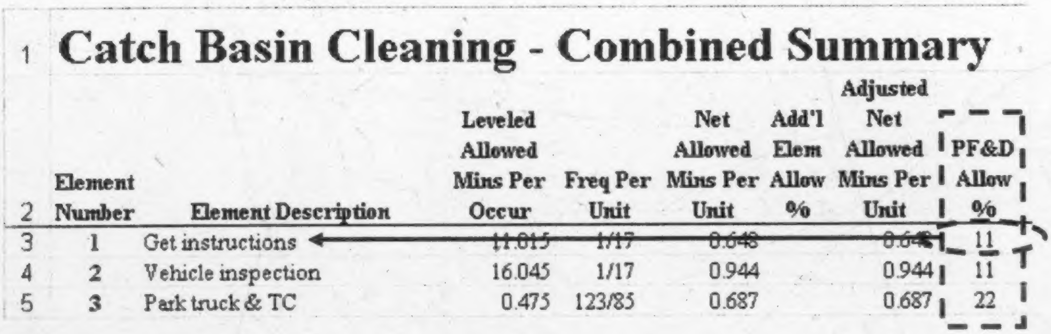
Std Man-hours/unit	0.429
Production Rate (CBC's per hour)	4.659
Daily Througkput (CBC's)	35.039

Std. Man-hours/unit = **1/I48**

Production Rate = **I48*2**

Productivity = **I55*8*0.94**

Figure 8: Additional performance calculations on spreadsheet



Catch Basin Cleaning - Combined Summary

2	Element Number	Element Description	Leveled Allowed Mins Per Occur	Freq Per Unit	Net Allowed Mins Per Unit	Add'l Elem Allow %	Adjusted Net Allowed Mins Per Unit	PF&D Allow %
3	1	Get instructions	11.015	1/17	0.648		0.648	11
4	2	Vehicle inspection	16.045	1/17	0.944		0.944	11
5	3	Park truck & TC	0.475	123/85	0.687		0.687	22

Figure 9: Personal, fatigue, and delay allowance shown for an element. Calculation is performed for each element.

Only relevant allowances are accounted for when determining allowances for each work element. Obtaining the allowances from Table 7, for the 'Get instructions' element allowance (Figure 9), the total allowance for that element is calculated as follows:

Personal Allowance = 5%, Basic Fatigue Allowance = 4%, Standing Allowance = 2%.

Therefore, Total Allowance = 5 + 4 + 2 = 11%

The production rate is determined by multiplying the number of crewmembers by the number of units per man-hour. The productivity is determined by multiplying the production rate by the number of hours per shift, and then multiplying by the availability of the crew to perform work during their shift. This crew availability is represented as a percentage of the entire shift. As a result, 0.94 represents the percentage of the shift that each crewmember is available for work, in other words, 94% of the shift is devoted to the catch basin cleaning work activity and takes into account the two 15 minute breaks required once every four hours or less. This multiplier comes from:

$$\frac{(8.0hr - (2 \times 0.25hr))}{8.0hr} = 0.94 \times 100\% = 94\%$$

Finally, the productivity is automatically computed on the spreadsheet as 35.039 locations (catch basins) per day (8-hr shift), which is interpreted as 35 (rounded). This value will be accounted for in deciding what will be determined as the productivity standard. The following section will review the steps to establishing and implementing a standard.

3.6 ESTABLISHMENT AND IMPLEMENTATION OF STANDARDS

The first step is for management to decide whether or not the current results (crew throughput) are realistically attainable by comparing current output to past performance as well as accounting for the amount of experience the crewmembers possess. The standards are typically represented in terms of man-hours per unit or units per man-hour; in addition other units of measurement were used, such as total units (throughput) either flushed, televised, or rodded per day. It is expected that crews may achieve, surpass, or fall short below the standard in their output. For this particular study, it was important to inform the workers that this standard is not established to be met on a daily basis; they are merely a means of gauging the crews' productivity of drainage work activities, to assist the management in their decision to improve the crews' performance, which translates potentially to financial and physical savings. In the CBC example, 35 units/day was deemed too low based on their historical performance (50 units/day). Therefore, once standards have been decided by management after verification using the output of the developed GPS models (40 units/day), compared to historical output, and based on observing the crews for a period of time, subsequent presentations and meetings between various foremen and workers occurred to reach a consensus on a standard that all parties agreed with. It was decided that 50 units (catch basins) was the standard to strive for. Table 12 displays all the engineered standards for the drainage operations maintenance crews as well as water consumption for the LPF, HPF, and MTV crews. The water consumption standards are determined through statistical analysis.

Table 12: Established productivity standards summary (Agbulos et al, 2003)

PRODUCTIVITY STANDARDS	CREW					
	CBC	***SLR[2]***	***CEI***	***LPF[3]***	***HPF***	***MTV***
UNITS	*Locations/day*	*Locations/day*	*Locations/day*	*Metres/day*	*Metres/day*	*Metres/day*
Standard man-hours/unit	0.301	3.76	0.752	0.008	0.0284	0.0625
Prod Std (units/man-hour)	3.32	0.211	1.75	125	35	16
Prod Rate (units/hour)	6.65	0.422	1.75	375	70	48
Daily Throughput[1] (Units)	50	4	10	2820	530	360
Expected Range (Units/day)	50 - 55	4 - 5	10 -11	2820 - 3102	530 - 583	360 - 396
Water Consumption (m^3/m)				0.0195	0.0221	0.0122

NOTE:

1. *Daily Throughput takes into account the crews' two 15-minute breaks using an availability of 94% for an 8-hour shift. It is calculated by multiplying the production rate by the shift length and the crews' availability. The production rate is calculated by multiplying the productivity standard by the number of workers on the crew. The productivity standard is derived from work measurement and the use of simulation.*
2. *SLR had worked an 8-hour shift until the year 2000. SLR now works a 10-hour shift with an expected daily throughput of 5 locations/day and range of 5 to 6 locations/day.*
3. *LPF Standard was set previously during Phase 2 of the study.*

Over a period of 20 days, verification of the developed productivity standards took place. The decision of 20 days was based on judgement sampling (Roesch, 2003). Utilizing tracking spreadsheets in Microsoft Excel®, Figures 10 and 11 demonstrate the effects of introducing the standards to the respective crews. As a rule-of-thumb, values above and below the standard (in daily throughput (units/day) or units/man-hour) by 10% is generally used in practice when explaining to the workers what management's perception, Drainage Operations' in this case, in terms of determining what is considered as acceptable performance compared to the standard.

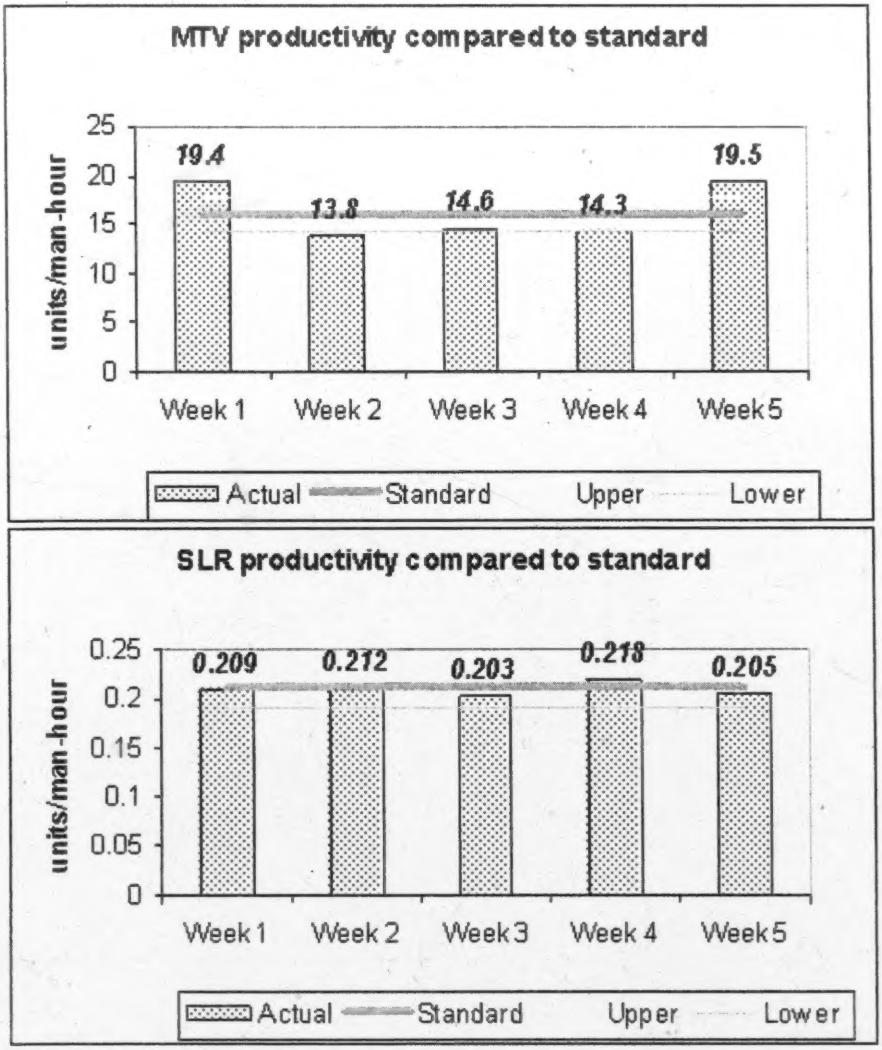


Figure 10: Results over 20-day period for MTV and SLR in units/man-hour (Agbulos et al, 2003)

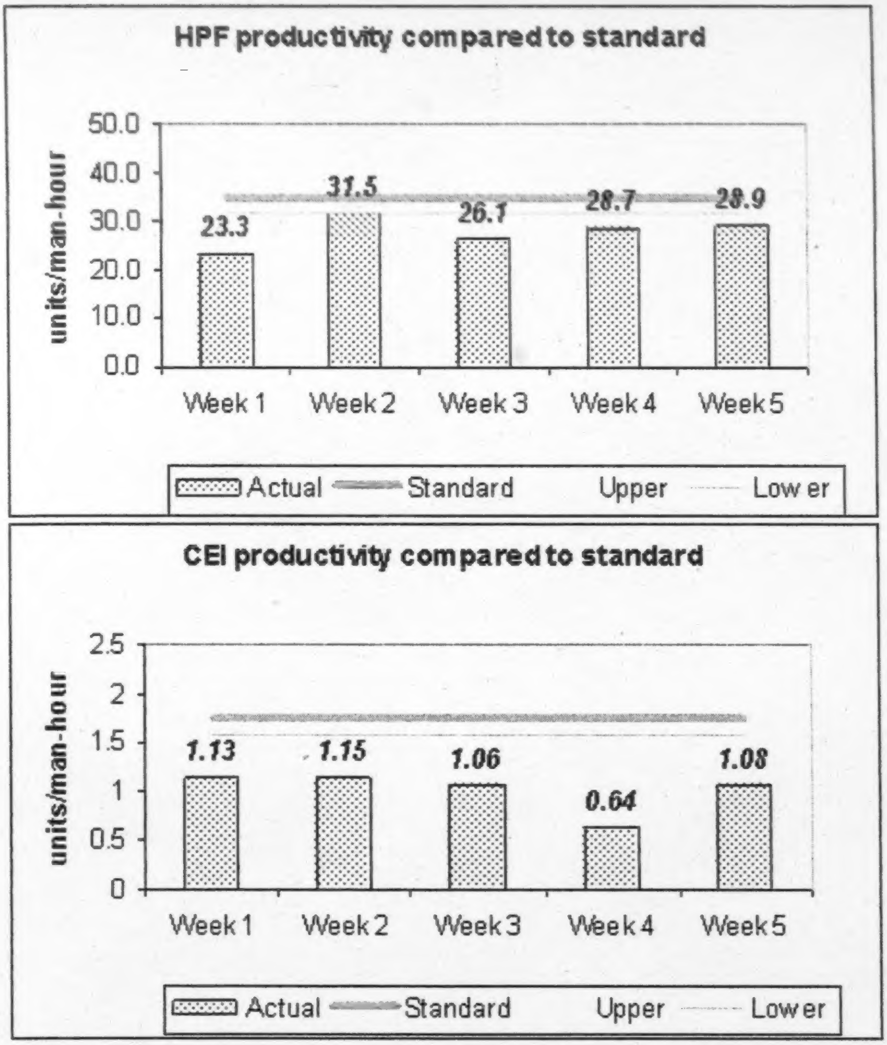


Figure 11: Results over 20-day period for HPF and CEI in units/man-hour (Agbulos et al, 2003)

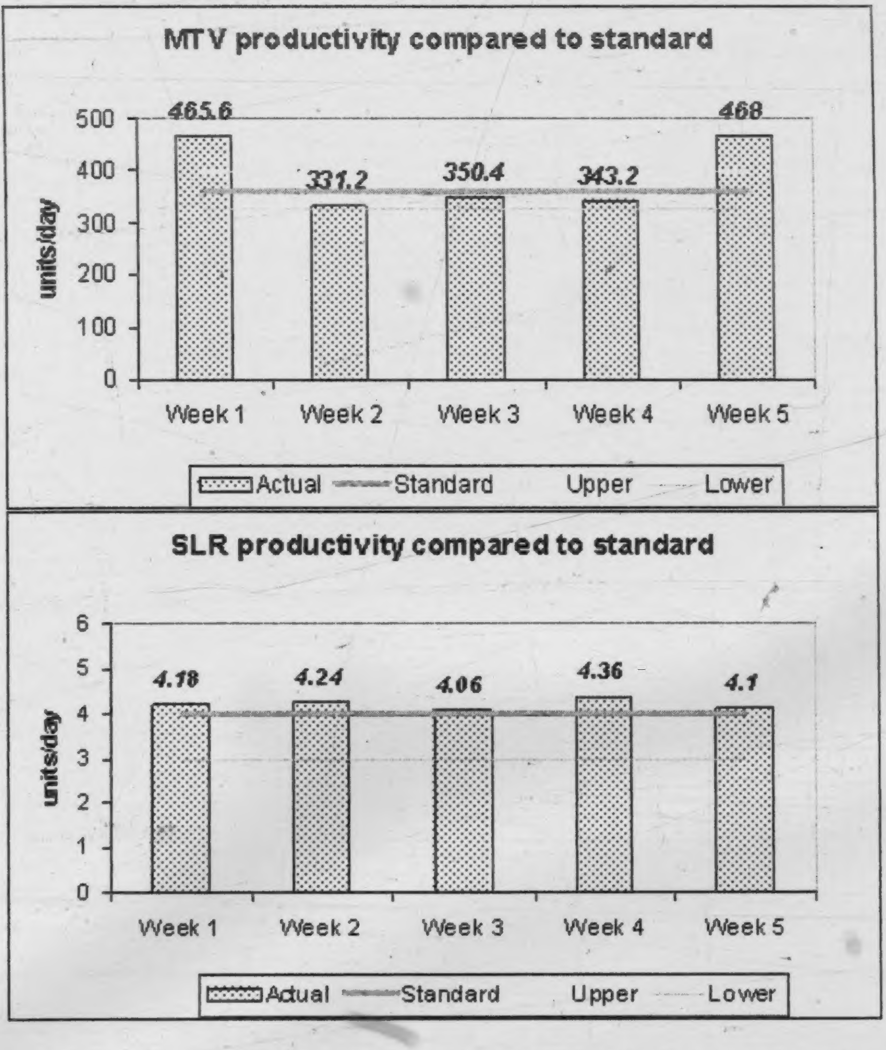


Figure 12: Results over 20-day period for MTV and SLR in units/day (Agbulos et al, 2003)

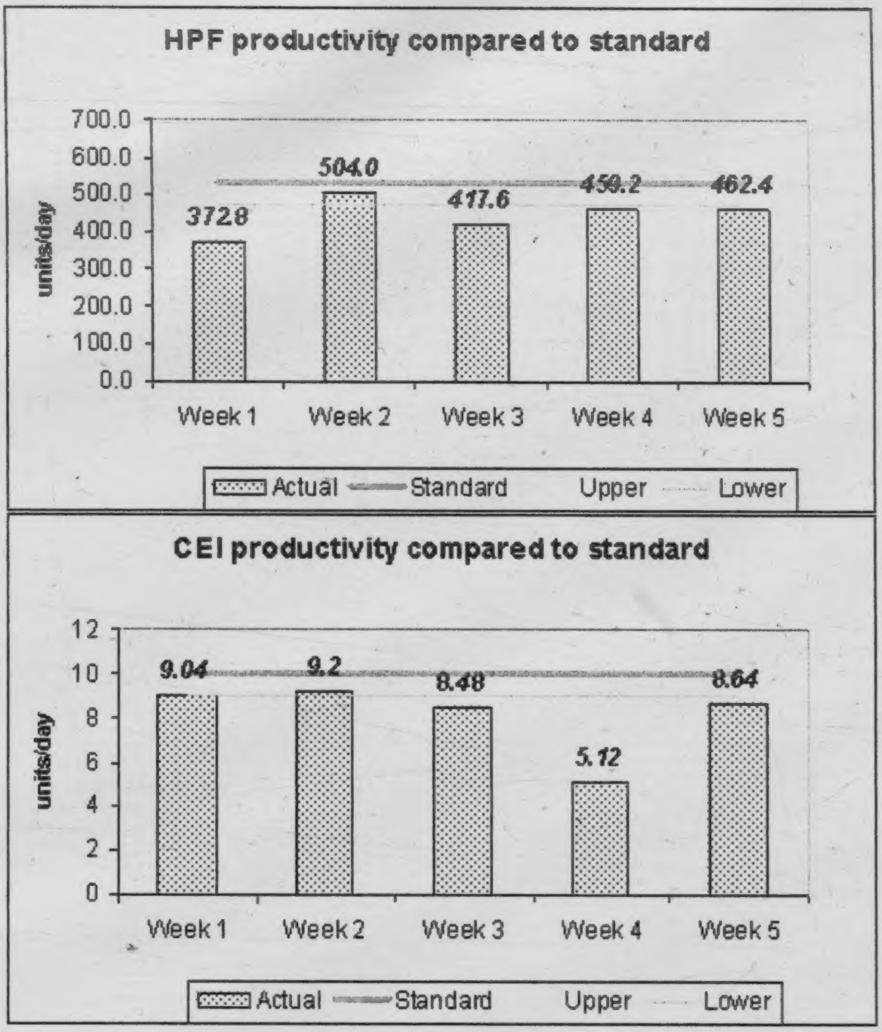


Figure 13: Results over 20-day period for HPF and CEI in units/day (Agbulos et al, 2003)

The productivity results over the 5-week period exemplify that the standards are adequate for the crews. However, the industrial waste inspectors of commercial establishment investigation and the crews for inspecting mains by high pressure flushing seemed to be underachieving. The standards developed for these two activities will not be changed because based on observing the crews during the data collection stage and consultation with drainage operations management, the workers should be capable of attaining these levels of productivity. Water consumption over the same timeframe was also tracked for the high pressure flushing and mainline televising activities. Figures 14 and 15 illustrate the water usage as compared to the standard. The results for water use by the mainline televising crews were tracked at a consistently lower level and therefore, a lower standard for water consumption was established based on the median value. *(Note: Standard for MTV water consumption was taken originally from HPF. Possible reasons for the lower amounts may be due to water consumption reports not being recorded by the workers on a daily basis.)*

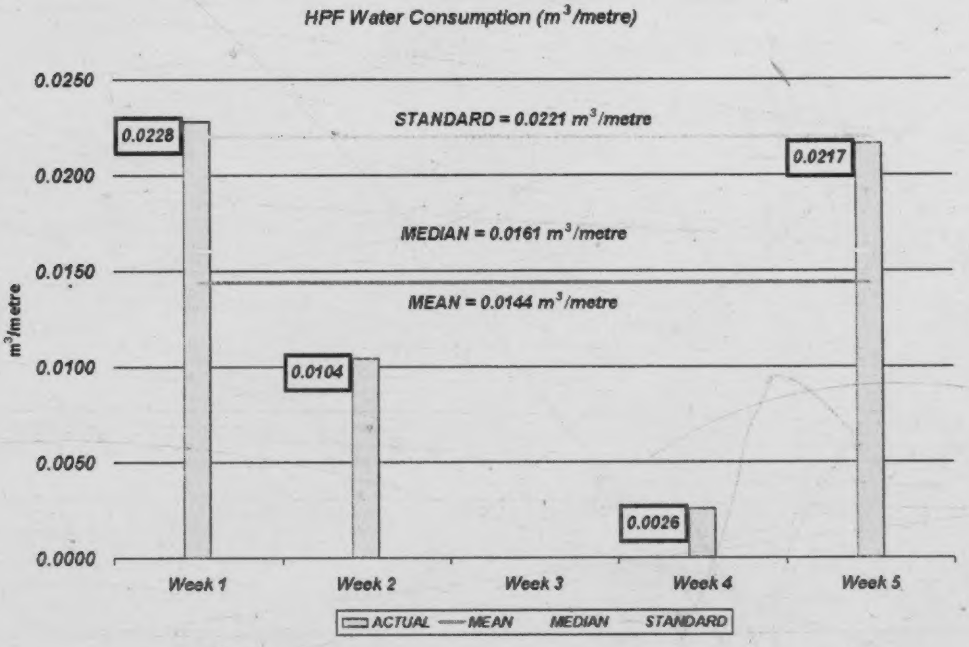


Figure 14: HPF water consumption over 20-day tracking period (Agbulos et al, 2003)

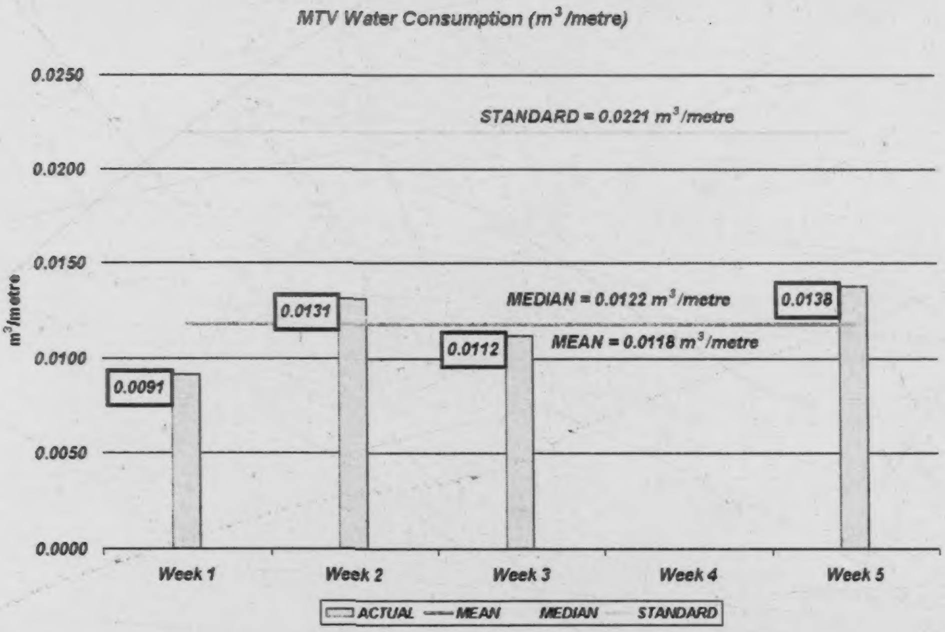


Figure 15: MTV water consumption over 20-day tracking period (Agbulos et al, 2003)

Comparisons to productivity standards and costs (labour/material/vehicle) associated with performing the six maintenance activities were also completed. Figures 16 through 19 demonstrate crews' performance based on comparing the expected and actual costs over the 5-week monitoring period. Generally, the costs associated with service line rodding and mainline televising seemed close to their expected results. However, the high pressure flushing and commercial establishment investigation activities revealed unit costs that were slightly and at times, moderately above their expected values. Figure 20 displays a portion of the typical tracking spreadsheet's comparison of expected versus actual costs. *(Note: The low pressure flushing activity was not monitored at this time since its productivity standard has already been developed and established. Catch basin cleaning was not tracked because the work was not performed during the verification period.)*

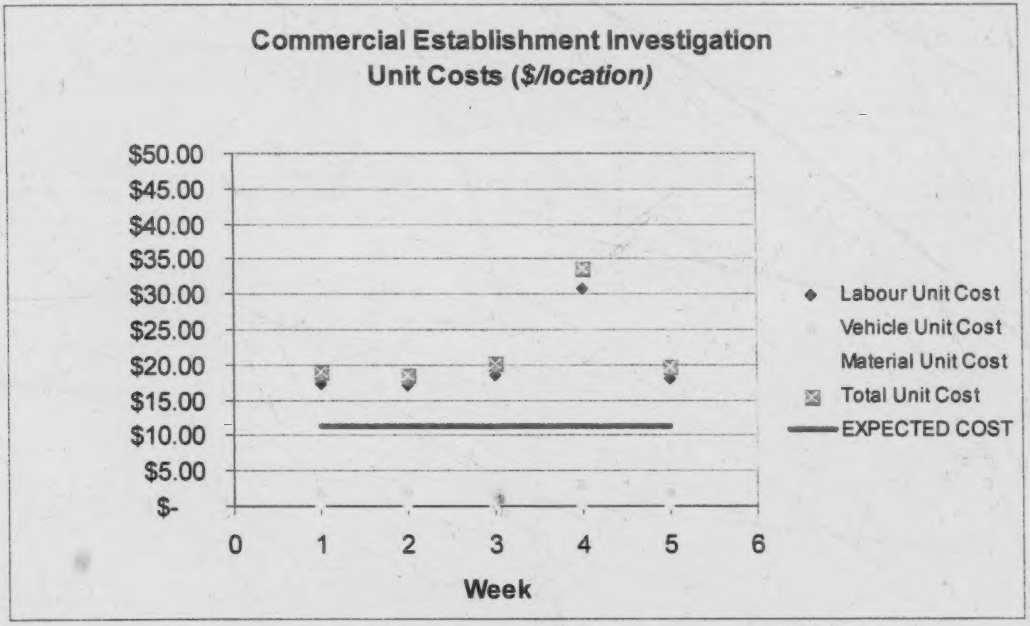


Figure 16: CEI Actual Unit Costs vs. Standard Unit Cost (Agbulos et al, 2003)

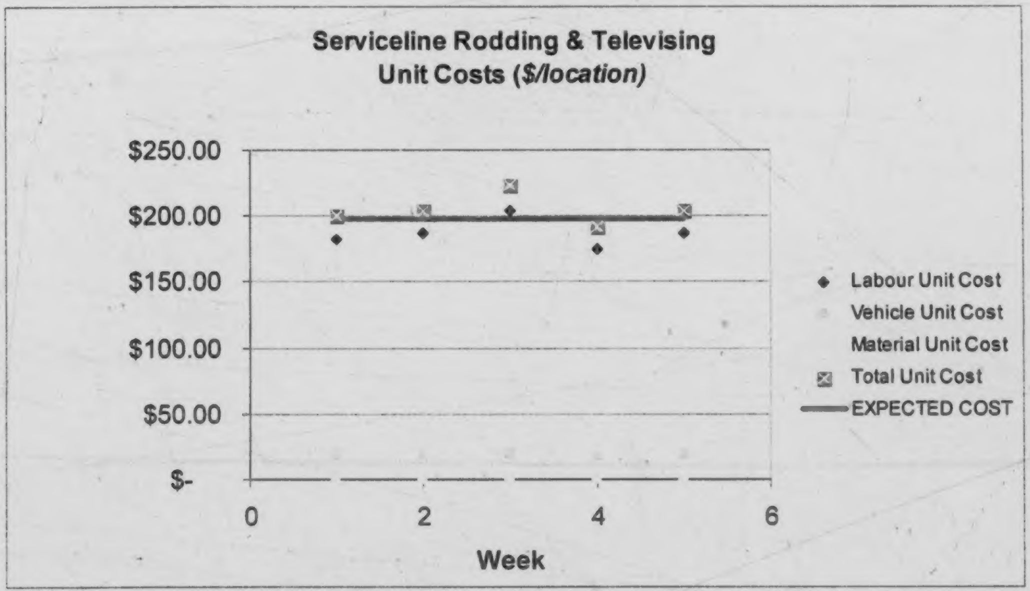


Figure 17: SLR Actual Unit Cost vs. Standard Unit Cost (Agbulos et al, 2003)

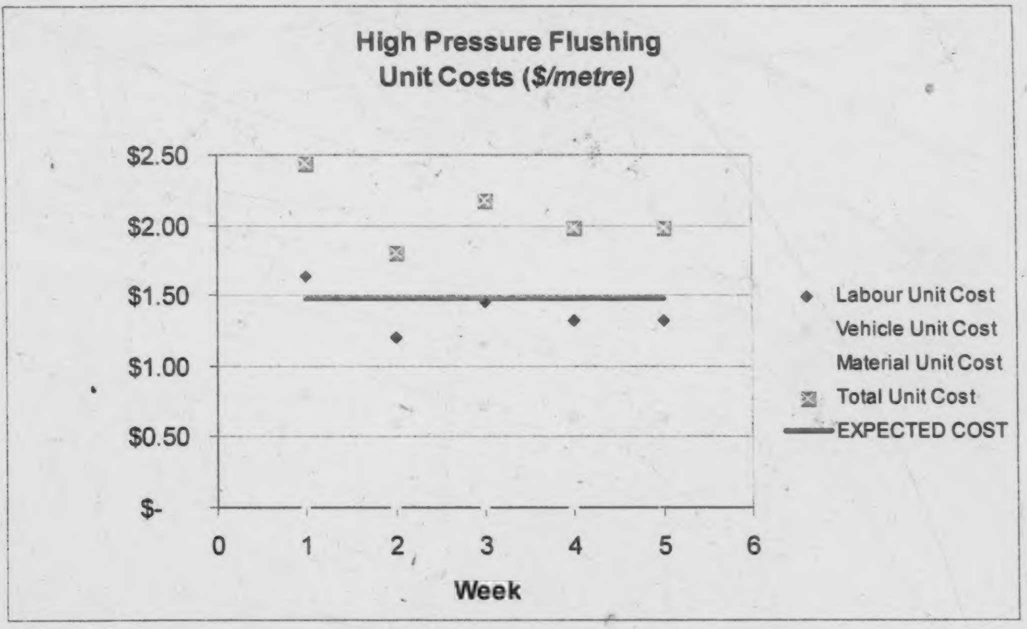


Figure 18: HPF Actual Unit Costs vs. Standard Unit Cost (Agbulos et al, 2003)

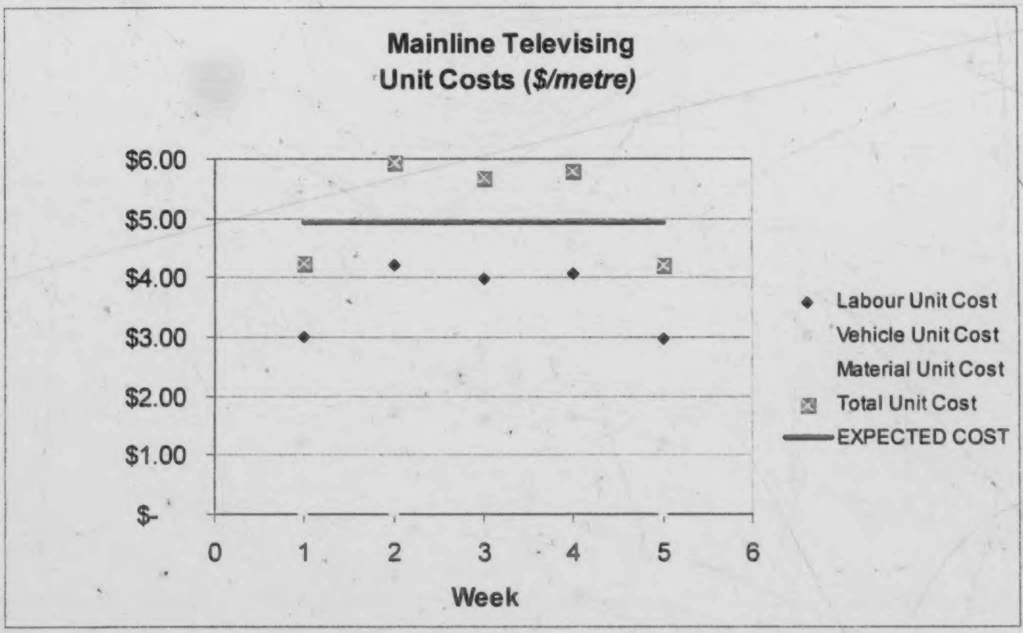
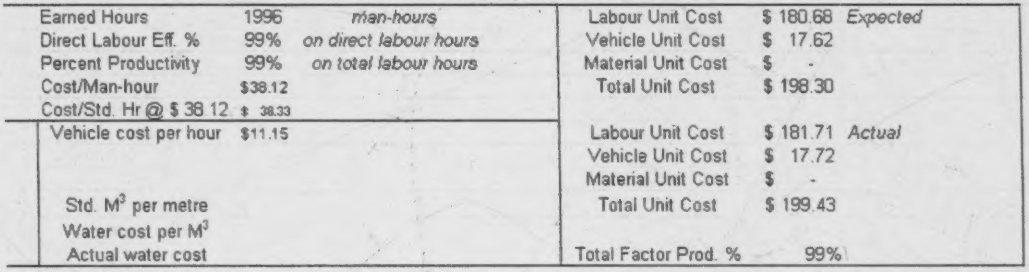


Figure 19: MTV Actual Unit Costs vs. Standard Unit Cost (Agbulos et al, 2003)



Earned Hours	1996	*man-hours*	Labour Unit Cost	$ 180.68	*Expected*
Direct Labour Eff. %	99%	*on direct labour hours*	Vehicle Unit Cost	$ 17.62	
Percent Productivity	99%	*on total labour hours*	Material Unit Cost	$ -	
Cost/Man-hour	$38.12		Total Unit Cost	$ 198.30	
Cost/Std. Hr @ $ 38.12	$ 38.33				
Vehicle cost per hour	$11.15		Labour Unit Cost	$ 181.71	*Actual*
			Vehicle Unit Cost	$ 17.72	
			Material Unit Cost	$ -	
Std. M^3 per metre			Total Unit Cost	$ 199.43	
Water cost per M^3					
Actual water cost			Total Factor Prod. %	99%	

Figure 20: Example of SLR productivity comparison using expected versus actual cost (Agbulos et al, 2003)

3.7 MAINTENANCE OF STANDARDS

Setting up standards is part of a goal-setting system, and control is essential to any goal-setting system. After successfully introducing the standards to the crews of the maintenance work activities, having a means of maintaining them is crucial while still maintaining safety regulations. The following steps were recommended (Salvendy, 2001).

1. **Reports** – performance should be fed back to both workers and management at least on a weekly basis.
    - Daily reports highlight delays and production problems;
    - Monthly reports smooth the fluctuations and show long-term trends.
2. **Rewards and Incentive**
    - Per stated time period based on discretion (monthly/quarterly/yearly, etc.) an award of recognition, time off (for those exceeding standard), or gift may change the mindset and improve the work environment/attitude
3. **Reasons for not meeting standard**
    - Consider learning – lack of satisfactory progress implies a need for training
    - Temporary set backs (**excusable**) → injuries, equipment failure, etc.
    - Experienced workers not performing to potential (**inexcusable**) → assess levels of discipline such as: oral warning, oral warning with detailed review, written warning, loss of pay, discharge, etc.

4. **Periodic Auditing Schedule** – sometimes a standard can restrict productivity if it has not been updated because workers will produce only to the obsolete standard and not their capabilities. Any significant changes to work methods may be a cause of obsolete standards and therefore, if necessary, the standard will have to be updated. Only the work elements affected will have to be re-timed and re-analyzed using time study. Re-training of workers is suggested. An expiration date should be set based on the rate of change in work methods. This may range from six months to four years from the time standards were introduced to maintenance crews. When the standard expires, and if it is still an active job (some activities operate year-round), an audit is made. If inactive (seasonal activities), the standard is given temporary status. Once inactive crews resume their duties, the temporary standard can be assessed for a stated time period (e.g. 30 days) until a new permanent standard is set. Expiration dates will give workers the sense of "not being picked on". If auditing resources are insufficient, only the "mighty few" and not the "insignificant many" will be audited. However, when the standard on one of the insignificant many passes the expiration date, convert the permanent standard to temporary.

3.8 COST SAVINGS

In addition to improving productivity, the amount of cost savings is significant. Based on the crews' historical daily throughput and assuming that the crews perform to the standard established, the total potential cost savings exceeds $ 316, 000. The breakdown of the cost for each crew is shown in Table 13. However, accounting for the LPF crews having already had their productivity standard established in 2001, demonstrated a cost saving of over $ 225, 000.

Table 13: Potential cost savings based on historical output (Agbulos et al, 2003)

5-Year Accumulated Average Daily Throughput (1995-2000)	CREW					
	CBC	*SLR*	*CEI*	*LPF*	*HPF*	*MTV*
Historic Daily Throughput	43	3.7	6.7	2194	525	346
% Productivity Gain	16	8	33	29	1	4
$ Cost Savings	**$45, 654**	**$85, 905**	**$53, 452**	**$90, 908**	**$13, 887**	**$25, 970**

3.9 CONCLUSIONS

This chapter presented the methodology used implement a system for work performance measurement and standards. The chapter also highlighted the steps required to maintain these standards. A comparison analysis to demonstrate the effect of the proposed work method on the maintenance crews productivities and cost saving.

Although developing a performance baseline (productivity and cost standard) is sufficient in improving productivity, the integration of simulation adds an additional dimension to the decision-making process for management. Chapter 4 will evaluate the effectiveness of combining current techniques with simulation methodology as was conducted for the low pressure flushing pilot study. The results obtained in the subsequent chapter are additional suggestions that may prove to be effective in further improving the productivity of the crews. The intent is to illustrate the potential improvements that can be achieved by applying lean theory using simulation analysis techniques.

CHAPTER 4: IMPLEMENTATION OF LEAN-THINKING USING GENERAL PURPOSE SIMULATION MODELS

4.1 OVERVIEW

All six crews were studied to improve their work methods; the LPF crews were chosen as the pilot study to undergo actual implementation improvements and monitoring of productivity after applying lean philosophy using simulation. Based on the success of that analysis performed for the LPF crew (see (Mohamed et al., 2002), the five remaining crews were modeled are their analysis is presented in this chapter The integration of lean concepts using simulation methodology will first be discussed in detail using the MTV crews. Finally, a similar but brief analysis of the other crews is presented. Drainage Operations management will decide whether or not these suggestions will be worthwhile to pursue.

4.2 LOW PRESSURE FLUSHING PILOT STUDY

This activity involves a crew consisting of three persons: Foreman I, Labourer I, and Labourer II. The objective is to supply water from a hydrant through a hose to the sewer line. This flow of water picks up accumulated debris from the feeder lines and moves it into the larger trunk lines where it then flows to the wastewater treatment plant. This crew will also respond to emergencies as necessary. Figure 21 shows a worker using a hydrant to provide water to the mainline.A full analysis of the study on this crew has been presented elsewhere, Mohamed et al 2002, and is briefly described here to provide continuity.

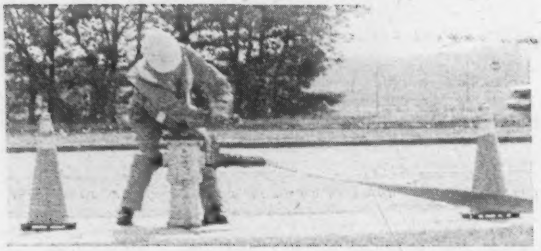


Figure 21: Opening the hydrant to permit water flow into mainline

4.2.1 RESULTS OF THE PILOT STUDY

Figure 22 shows the simulation model results based on the current (original) hierarchical scheme before applying the lean-thinking concept; where Figure 23 shows the simulation model results after the adaptation of lean theory. The simulation model provided an easy means of implementing different scenarios to improve productivity of the crews. Modifications such as elimination of the "surface inspection" step resulted in a productivity gain of 29% or 2820 metres/day, up from 2194 metres/day (as shown in Figure 24). As of November 2002, 3 out of the 5 crews met or exceeded the standard regularly. In addition to significant decrease in financial and human resources resulted from this study.

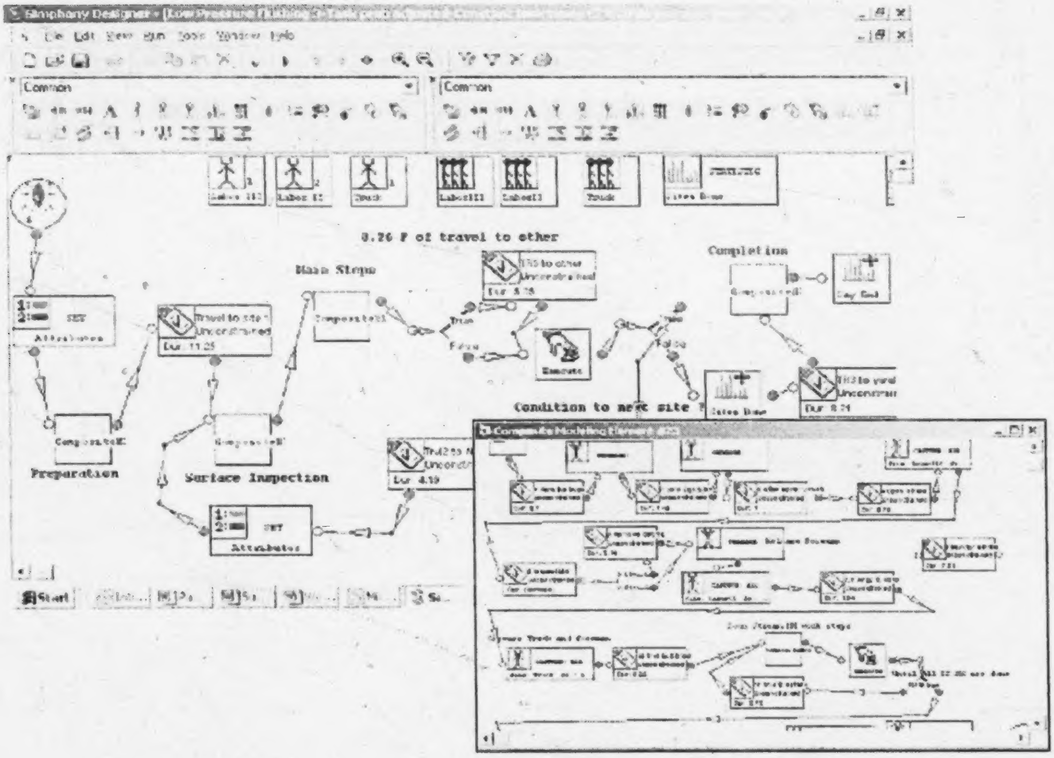
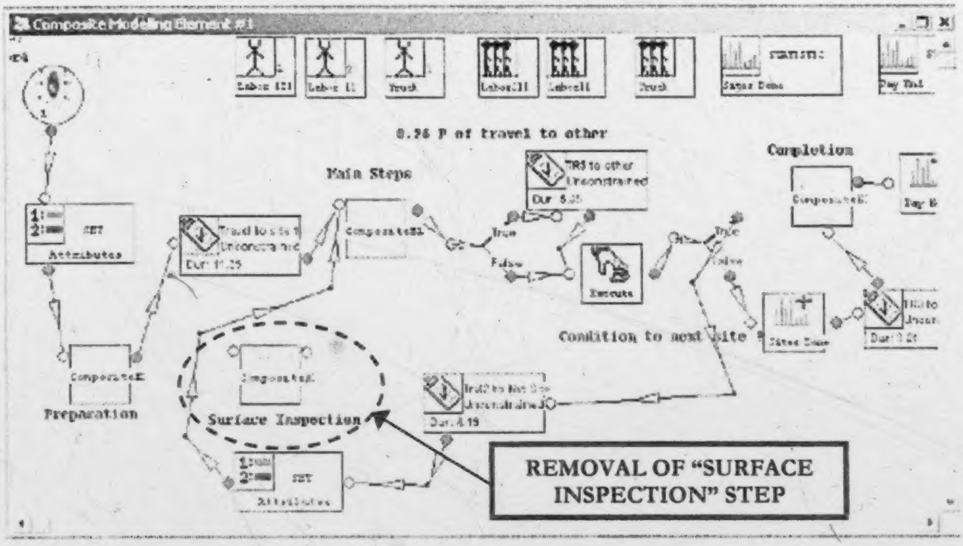

Simphony Designer
Common
0.26 P of travel to other
Main Steps
Completion
True
False
Execute
Condition to next site
SET
Attributes
Preparation
Surface Inspection
Composite Modeling Element
Start

Figure 22: LPF hierarchical model before study (Mohamed et al, 2002)


Composite Modelling Element #1
0.26 P of travel to other
Main Steps
Completion
True
False
Execute
Condition to next site
SET
Attributes
Preparation
Surface Inspection

REMOVAL OF "SURFACE INSPECTION" STEP

Figure 23: LPF model after study (Mohamed et al, 2002)

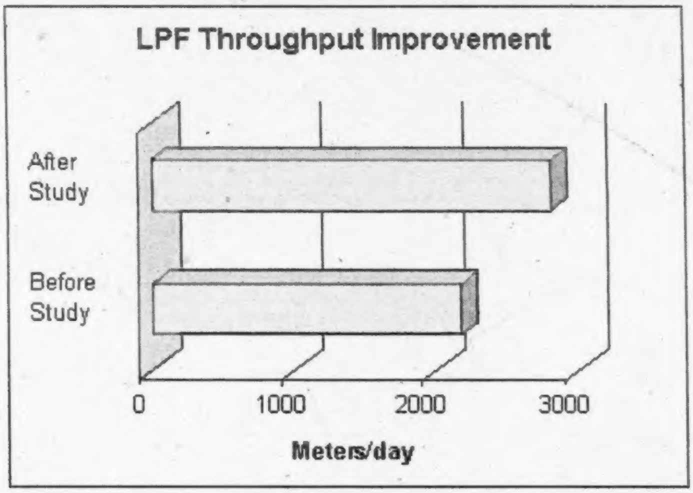


Figure 24: Productivity improvement of LPF (Agbulos et al, 2003)

4.3 MAINLINE TELEVISING (MTV) DETAILED EXAMPLE

This activity involves a crew consisting of three: Foreman I, Labourer II, and Equipment Operator III. The objective is to string a TV cable between two manholes and drawing a camera through the sewer mainline to inspect the pipe and record all deficiencies. As the camera records, an HPF crew simultaneously runs a high pressure flushing hose and nozzle repeatedly through the mainline to help the camera achieve the best picture possible. The crew will also respond to emergencies as necessary. Figure 25 shows the Foreman observing the TV unit.

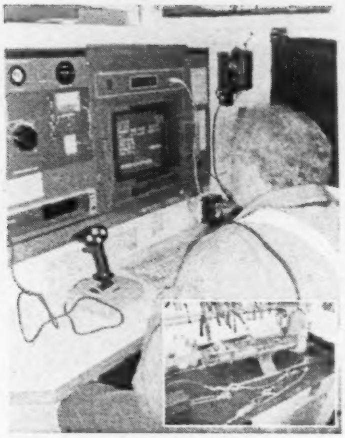


Figure 25: Foreman I operating the mainline camera (inset)

4.3.1 DESCRIPTION OF MTV ACTIVITY

The activity can be divided into three major tasks: (1) work preparation, (2) MTV work steps, and (3) work completion. Each of these components includes a series of tasks that are described.

1. *Work Preparation* – The foreman receives the work plan and instructs the high pressure flushing crew. A thorough vehicle check by both crews is performed to ensure that their vehicles are safe and functional to operate and that all equipment and materials necessary to perform the activity are present. After putting on personal protective equipment, the crews travel to the first location.
2. *MTV Work Steps* – The activity encompasses two separate activities working in parallel. Each worksite has several mainline stretches to be televised between manholes. The HPF unit located at the upstream manhole sets up as if completing the typical HPF activity. The labourer then walks to the TV unit. At the TV Unit location, the truck is parked and all traffic control devices are setup. All equipment is unloaded and then the downstream manhole is opened. After inspecting for deficiencies, the TV foreman starts the generator, prepares any relevant paper work, and enters any relevant information into the computer. Simultaneously, the labourer modifies the configuration of the camera (skid/crawler/float),

attaches the light, cleans the camera, and adjusts the camera's lead line (bullet). Next, the labourer and/or TV operator monitors the arrival of the HPF nozzle coming from the upstream manhole. The HPF is signalled of the arrival and the hose is snared up to the surface. The camera is attached to the nozzle, carefully lowered and positioned into the mainline. The hose pulls the camera 2 to 3.5 meters and is ordered by the TV foreman to stop. The invert roller assembly is placed over the manhole opening and then the sleeve is positioned into the entry point of the mainline to prevent any structural damage to the cable and hose. When setup is complete, the hose is ready to carefully guide the camera through the mainline (communication is extremely important). The record button is pressed on the VCR to initiate the inspection. As the inspection takes place, any deficiencies are documented. When the camera reaches the HPF manhole, the inspection is complete (VCR stops recording). While the camera is being rewound towards the TV unit, paper work is completed. When arrived at the manhole, the camera is pulled up and is detached from nozzle. All equipment used and traffic control devices are stored into the TV unit. The process may differ slightly if a crawler camera is used. The HPF unit follows typical equipment storage steps. The tasks regarding the connection to the nozzle of the flusher are ignored otherwise. When work at the location is complete, all setup and inspection activities are repeated until the end of the shift. If needed, the HPF unit may need to refill its water tank and/or vacuum debris.

3. *Work Completion* – Upon arrival at the yard, both the HPF and TV crewmembers clean, inspect, and store all equipment used during the shift. All paperwork is then submitted to the foreman.

4.3.2 SIMULATION APPLICATION FOR CURRENT MTV SITUATION

The current General Purpose Simulation (GPS) model is built in a hierarchy that represents different levels of detail for the activity. The highest level of the hierarchy (parent window) as shown in

Figure 26 represents the work preparation, work steps, work completion (end-of-day), and transportation elements. The actual mainline televising and high pressure flushing activities are found at the lower level of the hierarchy (child window) as shown in Figures 27 and 28. The base model created represents the current work method used by the crew. It simulates a typical workday not include delay time (lost time and productive foreign elements). The model runs for 100 simulation days to collect statistics on the number of meters televised per day. The model's output (shown in Figure 29) predicted the mean of 366.35 metres per day and it ranges from 215 to 508.30 metres per day.

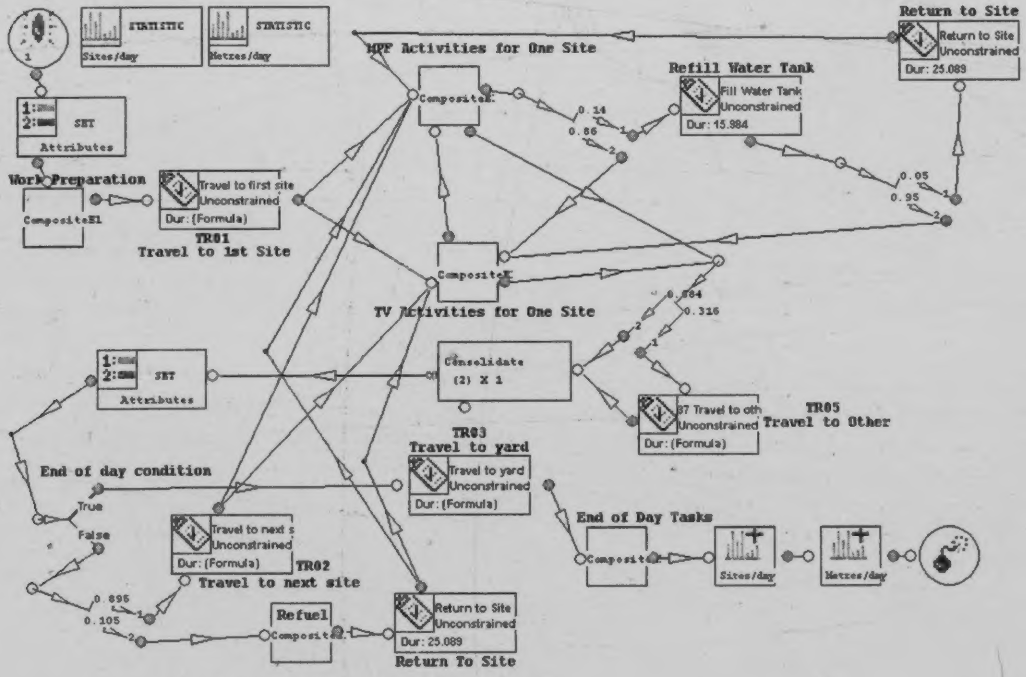

1
STATISTIC
Sites/day
STATISTIC
Metres/day
1:
2:
SET
Attributes
Work Preparation
CompositeE1
Travel to first site
Unconstrained
Dur: (Formula)
TR01
Travel to 1st Site
HPF Activities for One Site
CompositeE
0.14
0.86
1
2
Refill Water Tank
Fill Water Tank
Unconstrained
Dur: 15.984
Return to Site
Return to Site
Unconstrained
Dur: 25.089
0.05
0.95
1
2
CompositeE
TV Activities for One Site
0.684
0.316
2
1
1:
2:
SET
Attributes
Consolidate
(2) X 1
37 Travel to oth
Unconstrained
Dur: (Formula)
TR05
Travel to Other
TR03
Travel to yard
Travel to yard
Unconstrained
Dur: (Formula)
End of day condition
True
False
Travel to next s
Unconstrained
Dur: (Formula)
TR02
Travel to next site
0.895
0.105
1
2
Refuel
CompositeE
Return to Site
Unconstrained
Dur: 25.089
Return To Site
End of Day Tasks
CompositeE
Sites/day
Metres/day

Figure 26: Current MTV general purpose simulation parent window

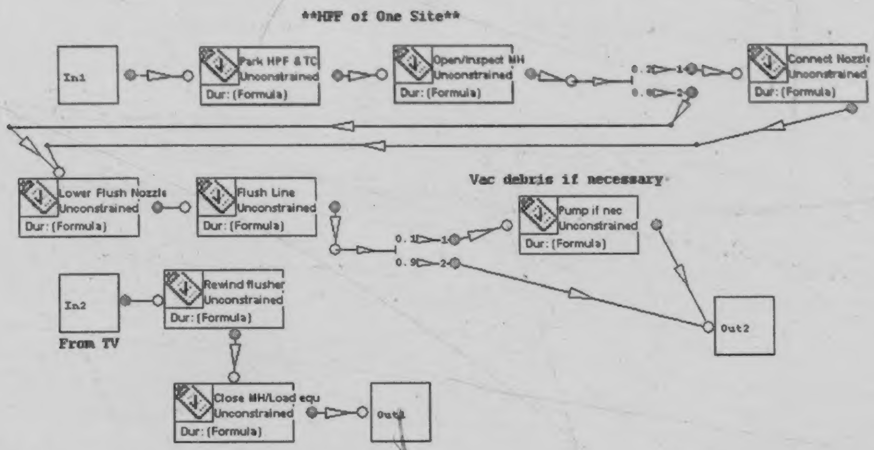

HPF of One Site
In1
Park HPF & TC
Unconstrained
Dur: (Formula)
Open/inspect MH
Unconstrained
Dur: (Formula)
0.2
1
0.8
2
Connect Nozzle
Unconstrained
Dur: (Formula)
Lower Flush Nozzle
Unconstrained
Dur: (Formula)
Flush Line
Unconstrained
Dur: (Formula)
Vac debris if necessary
Pump if nec
Unconstrained
Dur: (Formula)
0.1
1
0.9
2
Out2
In2
From TV
Rewind flusher
Unconstrained
Dur: (Formula)
Close MH/Load equ
Unconstrained
Dur: (Formula)
Out1

Figure 27: Current MTV general purpose simulation child window of "HPF of One Site"

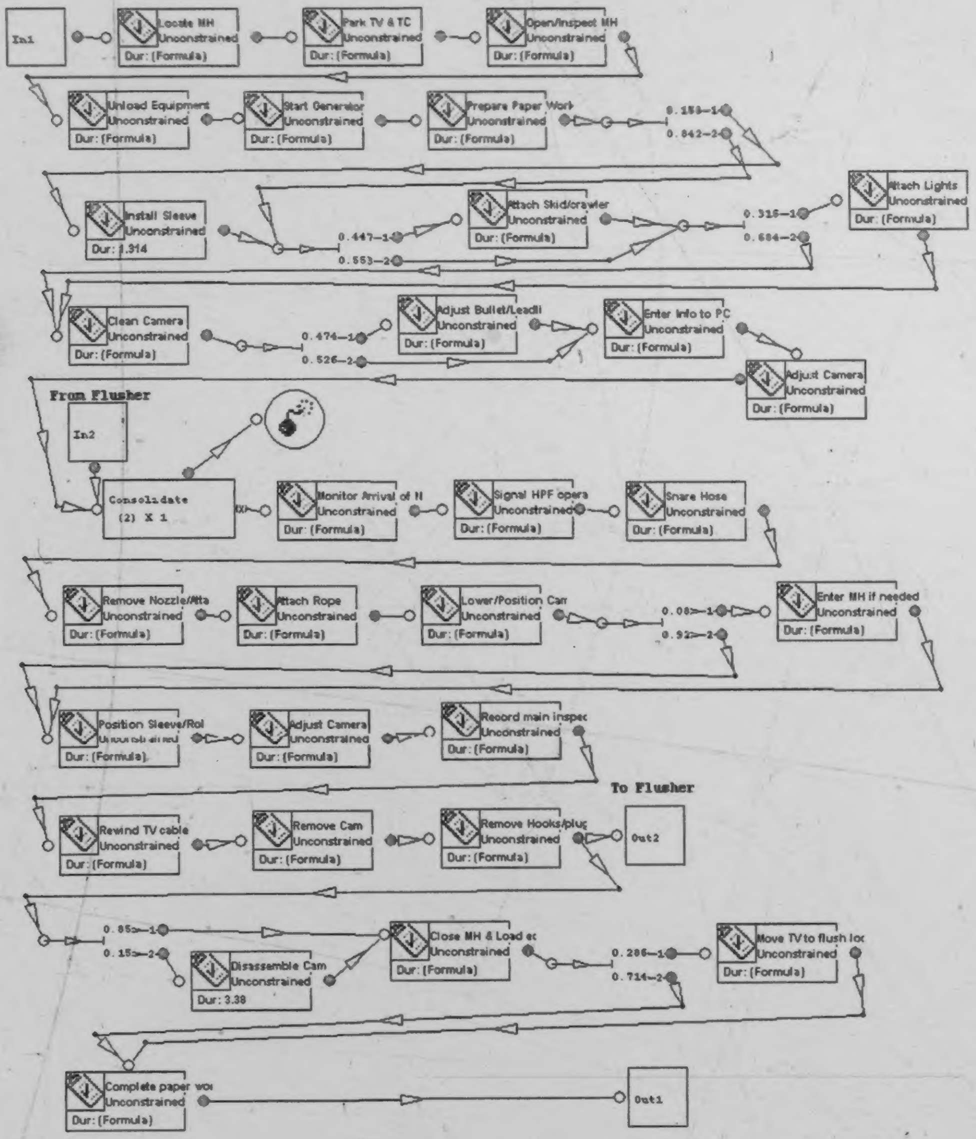
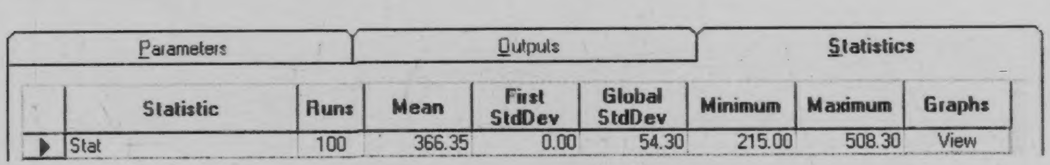

In1
Locate MH
Unconstrained
Dur: (Formula)
Park TV & TC
Unconstrained
Dur: (Formula)
Open/Inspect MH
Unconstrained
Dur: (Formula)
Unload Equipment
Unconstrained
Dur: (Formula)
Start Generator
Unconstrained
Dur: (Formula)
Prepare Paper Work
Unconstrained
Dur: (Formula)
0.158—1
0.842—2
Install Sleeve
Unconstrained
Dur: 1.314
0.447—1
0.553—2
Attach Skid/crawler
Unconstrained
Dur: (Formula)
0.316—1
0.684—2
Attach Lights
Unconstrained
Dur: (Formula)
Clean Camera
Unconstrained
Dur: (Formula)
0.474—1
0.526—2
Adjust Bullet/Leadli
Unconstrained
Dur: (Formula)
Enter Info to PC
Unconstrained
Dur: (Formula)
Adjust Camera
Unconstrained
Dur: (Formula)
From Flusher
In2
Consolidate
(2) X 1
Monitor Arrival of N
Unconstrained
Dur: (Formula)
Signal HPF opera
Unconstrained
Dur: (Formula)
Snare Hose
Unconstrained
Dur: (Formula)
Remove Nozzle/Atta
Unconstrained
Dur: (Formula)
Attach Rope
Unconstrained
Dur: (Formula)
Lower/Position Can
Unconstrained
Dur: (Formula)
0.08—1
0.92—2
Enter MH if needed
Unconstrained
Dur: (Formula)
Position Sleeve/Rol
Unconstrained
Dur: (Formula)
Adjust Camera
Unconstrained
Dur: (Formula)
Record main inspec
Unconstrained
Dur: (Formula)
To Flusher
Rewind TV cable
Unconstrained
Dur: (Formula)
Remove Cam
Unconstrained
Dur: (Formula)
Remove Hooks/plug
Unconstrained
Dur: (Formula)
Out2
0.85—1
0.15—2
Disassemble Cam
Unconstrained
Dur: 3.38
Close MH & Load ec
Unconstrained
Dur: (Formula)
0.286—1
0.714—2
Move TV to flush loc
Unconstrained
Dur: (Formula)
Complete paper wor
Unconstrained
Dur: (Formula)
Out1

Figure 28: Current MTV general purpose simulation child window of "TV Activities of One Site"


Parameters
Outputs
Statistics

	Statistic	Runs	Mean	First StdDev	Global StdDev	Minimum	Maximum	Graphs
▶	Stat	100	366.35	0.00	54.30	215.00	508.30	View

Figure 29: Simulation output using current MTV work method

4.3.3 LEAN-THINKING APPLICATION

The 1999 Efficiency Audit Report (Roesch, 2000) indicated that (MTV) crew was 78% efficient, which was well below the 90% criteria for being an efficient work crew. The principles of lean-thinking (synonymous with work simplification) are applied. The activity of Inspecting Mains by Televising was broken down to a number of tasks and then further subdivided into work elements for the time study. In addition, each element of the work process was designated as a value added (VA) or non-value added (NVA) work step (see Table 14). At this point, the areas for potential improvement for the maintenance activity process were identified. That is, the means of reducing the fraction of non-value added tasks to increase the fraction of value-added work steps was investigated. A minimum reasonable ratio between value added and non-value added is 50:50. Ideally, at the task level, a ratio of 80:20 should exist to minimize the amount of NVA steps in the entire business process. Typically for most business or industrial processes, if the NVA steps are not minimized at the task level, 90 to 98 % of the entire business process will end up being non-value added (see Section 3.3 for details). However, in this study, any improvement in the overall productivity of the crew is acceptable and demonstrates progress in the right direction. The breakdown of VA and NVA process steps for the Mainline Televising crews was 41% and 59% respectively as illustrated in Figure 28. Although the portion of VA steps was close to 50%, there is still room for improvement. This indicates that the crew is inefficient in work methods and in the deployment of workers and could have their performance increased significantly through the application of lean concepts, better scheduling, routing, and developed engineered productivity standards. The predominant NVA steps were transportation and delays, which accounted for 26% (110 minutes) and 16% (66 minutes) of the total time on the job. The 66 minutes of delay time consisted of excessive work (31% or 21 minutes), productive interruption (25% or 16 minutes), idle time and unrelated work (both at 12% or 8 minutes), instruction (11% or 7 minutes), and personal time (9% or 6 minutes).

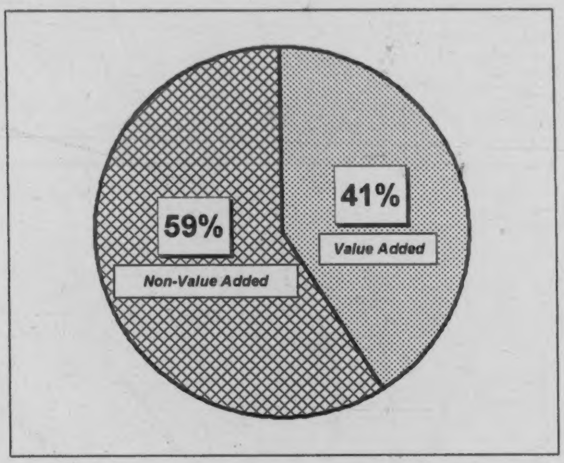


Figure 30: Current MTV Non-Value-Added versus Value-Added breakdown

Developing suggestions to improve performance and efficiency of the crew requires the consultation with training personnel, the crewmembers, management, and Occupational Health and Safety (OH&S). However, in this study, the suggestions presented were only discussed and supported by the Office of the City Auditor (OCA). Subsequently, the results of the study will be presented to the Drainage Operations management and it will be up to them to decide whether or not these propositions are acceptable. The 1999 Efficiency Audit (Roesch, 2000) proposed several improvements such as the need to reduce the number of crewmembers from three to two, but requires a safety examination. They determined that the use of three crewmembers was warranted based on the need that two crewmembers must remain on the surface while the third member enters the manhole to adjust the camera. Management needed to ascertain the feasibility of reducing the crewmembers based on actual manhole entry frequency. Possessing a crawler camera capable of transporting itself (and over small debris) through the mainline without the assistance of the flusher unit may affect the frequency of manhole entry. After careful consideration of the work elements and based on observing the crews over the data collection period and support from the OCA, the following additional modifications (other than those mentioned in the original efficiency audit), which were tested using the simulation model and were proposed for possible implementation..

- "Get Instructions" and "Give Instructions"
    - combining the two elements or eliminating "Give Instructions"
- "Unload Equipment" can be performed by labourer while foreman (TV operator) "Enters Info into the PC"
- "Install Sleeve" can be eliminated since it should always be installed (decreases handling time)
- "Attach Skid/Crawler", "Attach Light", and "Adjust Bullet/Lead Line" are handling steps that can be eliminated if a camera that is capable of transporting itself through the sewer mainline and over small quantities of debris, as illustrated in Figure 31 is used. This may reduce the frequency of manhole entry.

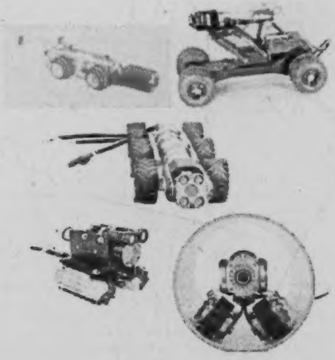


Figure 31: Various mainline cameras <internet websites 3, 4, 8, and 10>

- An automated means of "Completing Paper Work" could be developed to reduce the time it takes to perform these steps. However, a fair amount of development and training would have to be provided in order to implement such a system (see Section 4.10.2). The current cycle time for "Completing Paper Work" is 14.61 minutes, which could be reduced to an educated guess of 10 minutes.

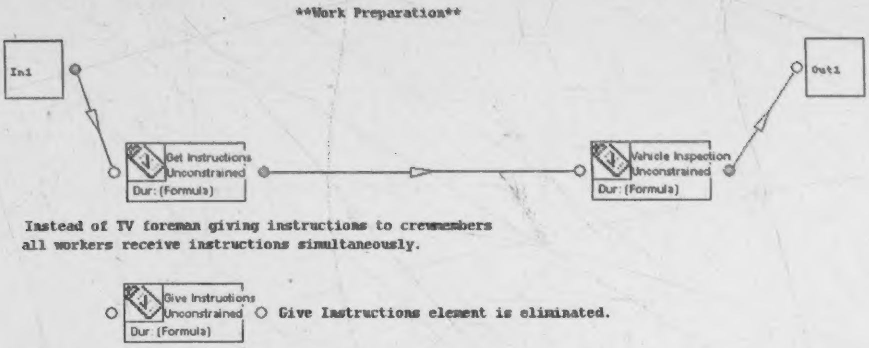
Table 14: Element breakdown (MTV) and VA/NVA identification

Element	*Process Step Cycle Time*[1]	*Normal Time (xfrequency)*	*Process Step*	*Symbol*	*VA/NVA*
Work Preparation					
Get Instructions	5.98	7.77(x0.77)	Operation	●	VA
Give Instructions	1.20	1.41(x0.85)	Operation	●	VA
Vehicle Check	5.45	6.41(x0.85)	Inspection	■	NVA
Work Steps					
Locate MH	3.54	1.35(x2.62)	Inspection	■	NVA
Park TV Truck/Traffic Control	7.63	2.42(x3.15)	Operation	●	VA
Unload Equipment	4.57	1.32(x3.46)	Handling	➡	NVA
Open/Inspect MH(TV)	4.42	1.47(x3.00)	Inspection	■	NVA
Park HPF Truck/Traffic Control	2.66	1.92(x1.38)	Operation	●	VA
Open/Inspect MH(F)	0.87	0.60(x1.46)	Inspection	■	NVA
Connect flusher nozzle	0.25	0.80(x0.31)	Handling	➡	NVA
Lower flusher nozzle	2.39	1.63(x1.46)	Handling	➡	NVA
Flush Line/Monitor	32.72	20.20(x1.62)	Operation	●	VA
Pump debris if necessary	1.31	8.74(x0.15)	Operation	●	VA
Walk to/assist TV(F)	0.69	0.90(x0.77)	Operation	●	VA
Install Sleeve (TV)	0.60	1.31(x0.46)	Handling	➡	NVA
Start generator (TV)	0.69	0.52(x1.31)	Operation	●	VA
Prepare Paper Work	16.01	6.30(x2.54)	Operation	●	VA
Attach skid/crawler (TV)	9.76	6.68(x1.46)	Handling	➡	NVA
Attach light (TV)	1.88	1.88(x1.00)	Handling	➡	NVA
Clean Camera	1.84	0.92(x2.00)	Operation	●	VA
Adjust Bullet/Lead Line (TV)	5.15	3.73(x1.38)	Handling	➡	NVA
Monitor Arrival of Nozzle (TV)	4.49	2.09(x2.15)	Inspection	■	NVA
Signal HPF Operator	0.42	0.22(x1.92)	Operation	●	VA
Enter info to PC	5.56	2.26(x2.46)	Operation	●	VA
Remove Nozzle/Attach Camera	2.04	0.83(x2.46)	Handling	➡	NVA
Attach Rope	0.26	0.30(x0.85)	Handling	➡	NVA
Lower/Position Camera	7.24	2.35(x3.08)	Handling	➡	NVA
Position Sleeve/Roll	2.34	0.78(x3.00)	Handling	➡	NVA
Adjust Camera	2.35	1.33(x1.77)	Handling	➡	NVA
Record Main Inspection	33.51	11.48(x2.92)	Operation	●	VA
Rewind TV cable	10.57	4.44(x2.38)	Operation	●	VA
Enter MH if needed	2.74	11.92(x0.23)	Operation	●	VA
Remove Camera/Drop Cable	3.77	1.32(x2.85)	Handling	➡	NVA
Remove Hooks/Plugs	0.80	0.39(x2.08)	Handling	➡	NVA
Rewind Flusher Hose	4.41	3.02(x1.46)	Operation	●	VA
Disassemble Camera	1.55	3.38(x0.46)	Handling	➡	NVA
Close MH/Load Equipment	11.06	2.66(x4.15)	Operation	●	VA
Move TV Unit to Flusher	0.92	2.42(x0.38)	Transportation	→	NVA
Complete Paper Work	14.61	4.32(x3.38)	Operation	●	VA
Signal Foreman	0.03	0.12(x0.23)	Operation	●	VA
Inform Customer	0.53	6.59(x0.08)	Operation	●	VA
Snare Hose	3.05	2.09(x1.46)	Handling	➡	NVA
Fill Water Tank	3.68	15.98(x0.23)	Operation	●	VA
Work Completion					
Clean Equipment	8.55	3.59(x2.38)	Operation	●	VA
Inspect Equipment	0.17	2.08(x0.08)	Inspection	■	NVA
Store Equipment	2.86	3.72(x0.77)	Storage	▼	NVA
Submit Forms	1.69	1.84(x0.92)	Operation	●	VA
Travel Times and Refuelling					
Travel to 1st site	25.43	25.43(x1.00)	Transportation	→	NVA
Travel to Next Site	28.95	12.16(x2.38)	Transportation	→	NVA
Travel to Yard	35.60	27.17(x1.31)	Transportation	→	NVA
Travel to Gas Station	3.10	9.99(x0.31)	Transportation	→	NVA
Travel to Other ( )	13.28	9.99(x0.92)	Transportation	→	NVA
Refuel	1.80	5.82(x0.31)	Operation	●	VA
Return To Site	3.76	25.09(x0.15)	Transportation	→	NVA
Delays (Lost Time and Productive Foreign Elements)					
Lost Time					
Idle Time	8.08	8.08	Delay	◗	NVA
Excessive Work	20.55	20.55	Delay or Rework	◗ | Ⓡ	NVA
Personal Time	5.88	5.88	Delay	◗	NVA
Instruction	7.33	7.33	Delay	◗	NVA
Productive Foreign Elements					
Productive Interruption	16.48	16.48	Delay	◗	NVA
Unrelated Work	8.17	8.17	Delay	◗	NVA

Note: 1. Accumulated amount over entire shift. E.g. "Record Main Inspection". Normal time= total raw time/#obs=436.1/38=11.48 minutes
Process step cycle time for "Record Main Inspection"=(normal time)*(frequency)=(11.48)*(2.92)=33.51 minutes

4.3.4 APPLIED LEAN-THINKING USING SIMULATION

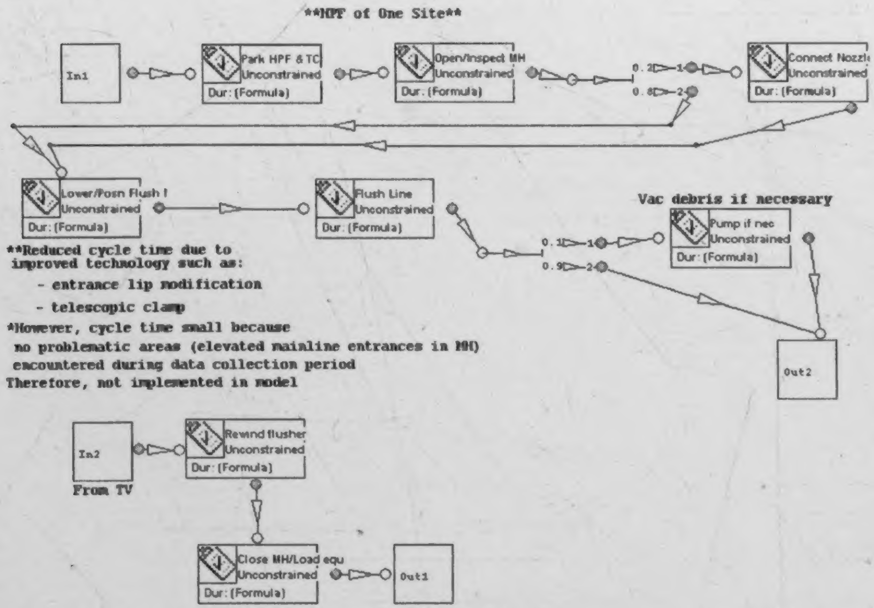
Figures 32, 33, 34, and 35 illustrate the suggestions discussed as implemented within the simulation model. During the "Work Preparation" task, the smaller cycle time (1.20 minutes) of "Give Instructions" is eliminated and assumed to take place during the larger cycle time (5.98 minutes) of "Get Instructions" to create a combined "Get/Give Instructions" element. The most significant changes occurred at the location where the mainline televising unit is situated. By introducing a camera that does not require the guidance of the high pressure flushing unit, a number of handling (non-value adding or waste) work steps can be eliminated: "Attach Skid/Crawler", "Attach Light", "Adjust Bullet/Lead Line", "Remove Nozzle/Attach Camera", "Attach Rope", "Remove Hooks/Plugs", and "Snare Hose". As well, "Install Sleeve", a non-value adding work step, was eliminated. This decreases the portion of non-value added tasks and increases the portion of value-added tasks considerably. In terms of the implementation of an organizational-wide automated labour tracking timesheet system, an educated guess of 10 minutes was assumed based on observing the crew during the data collection period as well as several viewings of a videotaped recording of the work process. After implementing the suggestions, the improvement in productivity (as illustrated in Figure 36) went from 360.72 meters per day to 382.08 meters per day. An increase of 21.36 meters televised per day or 5.9 % proves that an enhancement of productivity in the simulation model by lean thinking is possible. This increase may even translate to flushing another stretch between manholes that is approximately 20 meters in length. Figure 37 illustrates the difference in productivity gained before and after lean application. For instance, at a probability of 55%, the productivity is higher for the modified work method than the current work method.


Work Preparation
In1
Get Instructions
Unconstrained
Dur: (Formula)
Vehicle Inspection
Unconstrained
Dur: (Formula)
Out1
Give Instructions
Unconstrained
Dur: (Formula)

Instead of TV foreman giving instructions to crewmembers all workers receive instructions simultaneously.

Give Instructions element is eliminated.

Figure 32: Eliminated "Give Instructions" element during "Work Preparation" after lean-thinking

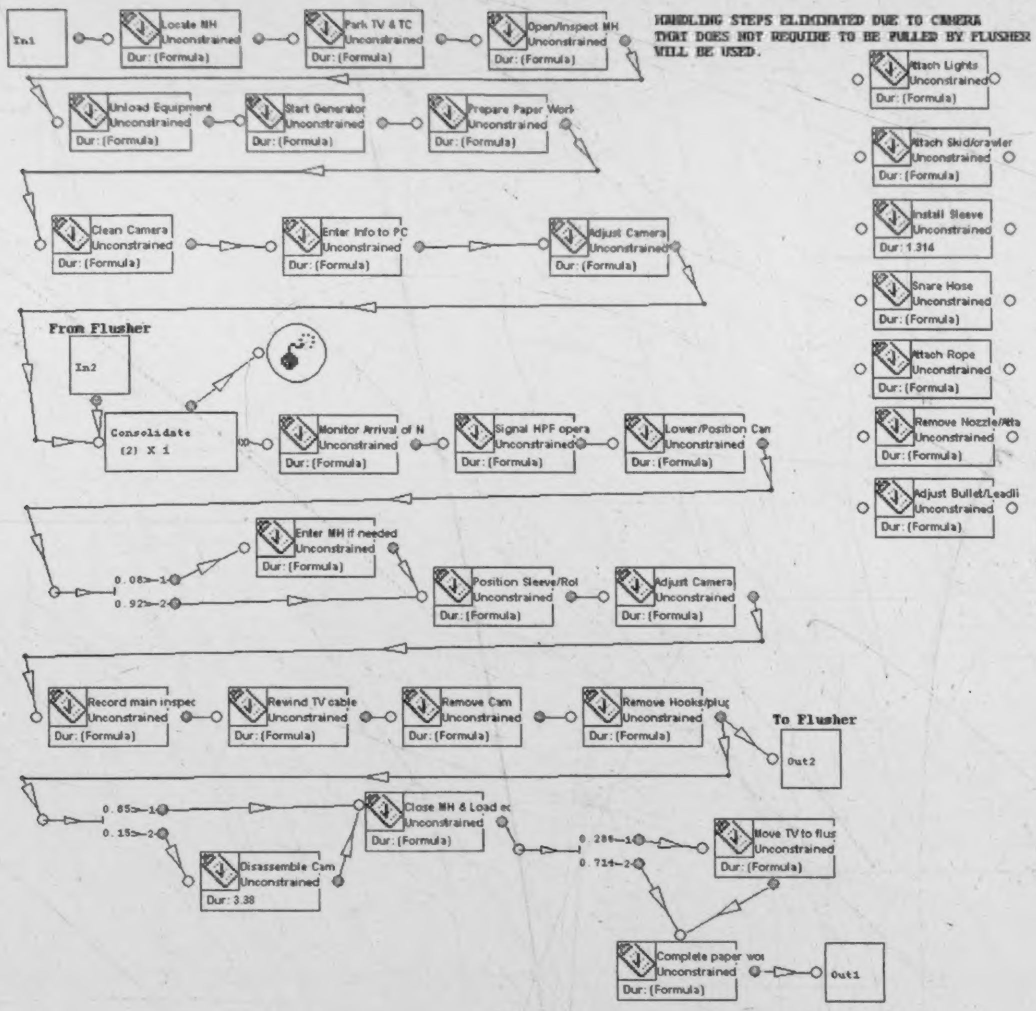

HPF of One Site
In1
Park HPF & TC
Unconstrained
Dur: (Formula)
Open/Inspect MH
Unconstrained
Dur: (Formula)
0.2
1
0.8
2
Connect Nozzle
Unconstrained
Dur: (Formula)
Lower/Posn Flush I
Unconstrained
Dur: (Formula)
Flush Line
Unconstrained
Dur: (Formula)
Vac debris if necessary
0.1
1
0.9
2
Pump if nec
Unconstrained
Dur: (Formula)
Out2
In2
From TV
Rewind flusher
Unconstrained
Dur: (Formula)
Close MH/Load equ
Unconstrained
Dur: (Formula)
Out1

**Reduced cycle time due to improved technology such as:

- entrance lip modification
- telescopic clamp

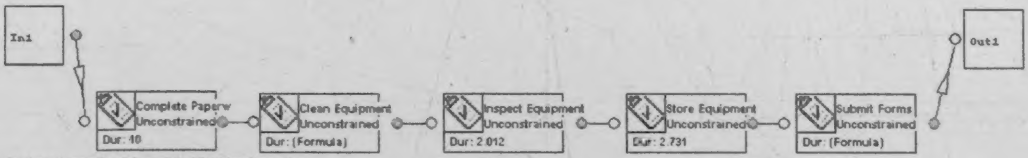
*However, cycle time small because no problematic areas (elevated mainline entrances in MH) encountered during data collection period
Therefore, not implemented in model

Figure 33: Reduced cycle time for "Lower/Position Nozzle" element not implemented in model


HANDLING STEPS ELIMINATED DUE TO CAMERA THAT DOES NOT REQUIRE TO BE PULLED BY FLUSHER WILL BE USED.

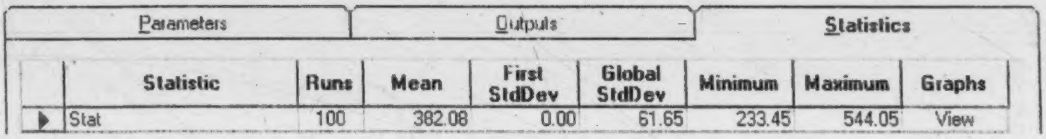
In1
Locate MH
Unconstrained
Dur: (Formula)
Park TV & TC
Open/Inspect MH
Unload Equipment
Start Generator
Prepare Paper Work
Clean Camera
Enter Info to PC
Adjust Camera
From Flusher
In2
Consolidate
(2) X 1
Monitor Arrival of N
Signal HPF opera
Lower/Position Can
Enter MH if needed
0.08
0.92
Position Sleeve/Rol
Adjust Camera
Record main inspec
Rewind TV cable
Remove Cam
Remove Hooks/pluç
To Flusher
Out2
0.85
0.15
Close MH & Load ec
Disassemble Cam
Dur: 3.38
0.286
0.714
Move TV to flus
Complete paper wo
Out1
Attach Lights
Attach Skid/crawler
Install Sleeve
Dur: 1.314
Snare Hose
Attach Rope
Remove Nozzle/Atta
Adjust Bullet/Leadli

Figure 34: Eliminated handling elements in MTV work method after lean-thinking


In1
Complete Paperw
Unconstrained
Dur: 10
Clean Equipment
Dur: (Formula)
Inspect Equipment
Dur: 2.012
Store Equipment
Dur: 2.731
Submit Forms
Out1

Reduced cycle time to 10 minutes due to automated labour tracking system

Figure 35: Reduced cycle time of "Complete Paper Work" element after lean-thinking



	Statistic	Runs	Mean	First StdDev	Global StdDev	Minimum	Maximum	Graphs
▶	Stat	100	382.08	0.00	61.65	233.45	544.05	View

Figure 36: MTV simulation output after lean-thinking

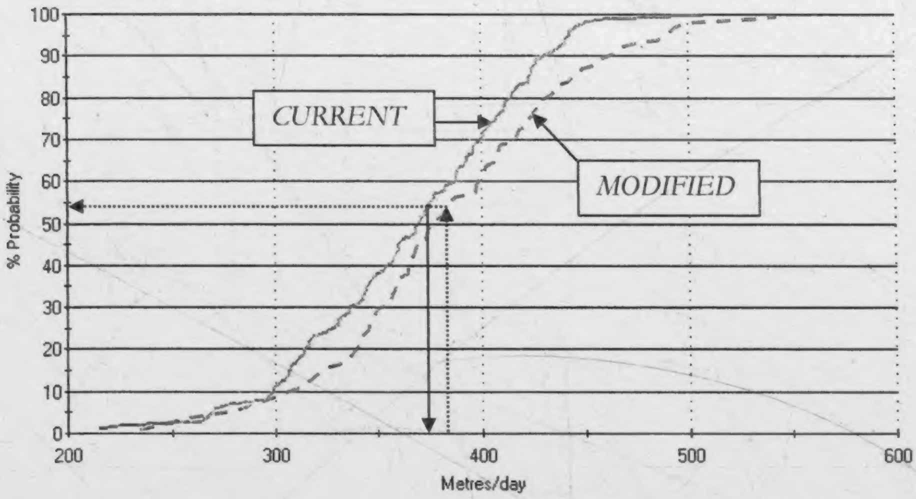


Figure 37: Cumulative distribution function of MTV before and after lean-thinking

Though an improvement in productivity is evident, the changes made to the current mainline televising work method should warrant future industry implementation and measurement to verify the accuracy of the results. However, the suggestions should never be implemented without having consulted with Occupational Health and Safety, training personnel, and Drainage Operations management. The omission of modeling the delay elements could be the difference in increasing the improvement even further. Decreasing the overall delay time (non-value added elements or waste) should have a positive effect by increasing the portion of value-added tasks and consequently assisting the crews to reach an even higher productivity rate. A cost-benefit analysis would have to be carried out in order for management to decide whether progression into new technology for the productivity improvement of the drainage operations maintenance crews is feasible. Table 20 summarizes the suggestions for the other remaining crews. See Table 21 for a complete summary of results.

4.4 REMAINING DRAINAGE OPERATIONS MAINTENANCE CREWS

By taking advantage of the performance improvement process of mainline televising, similar steps are taken and implemented to the four remaining crews including commercial establishment investigation, service line rodding, catch basin cleaning, and high pressure flushing

4.4.1 COMMERCIAL ESTABLISHMENT INVESTIGATION (CEI)

The position of industrial waste inspector can involve a variety of tasks such as sampling, sewage odour investigation, customer drainage problem investigation, pollutant spill maintenance and investigation, and finally, smoke and dye testing. In this study, specific attention was given to Commercial Establishment Inspection. The activity encompasses one inspector whose responsibility at the City of Edmonton is to visit various commercial establishments and inspects grease traps to ensure that proper grease disposal measures have been taken. Figure 38 shows an industrial waste inspector performing the CEI activity.

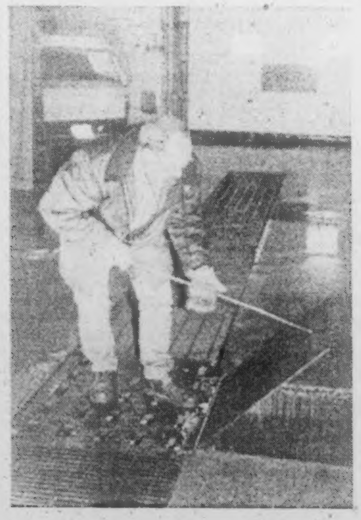


Figure 38: Example of CEI activity at an undisclosed location

4.4.2 DESCRIPTION OF CEI ACTIVITY

The activity can be divided into two major components: (1) work preparation steps and (2) CEI work steps. Each of these components includes a series of tasks that are described.

1. *Work Preparation* – At this time, the industrial waste inspector consults with his/her superior to determine the schedule and the areas of the city and commercial establishments to concentrate his/her inspection activities on. A thorough vehicle check is performed to ensure that the vehicle is safe and functional to operate and that all equipment and materials necessary to perform the activity are present. The inspector then drives to the first work location.
2. *CEI Work Steps* – Each commercial establishment has some type of container that stores grease. After locating the grease trap, the inspector opens and inspects the trap (or drain). The customer (employee or manager of establishment) is notified of any problems and concerns regarding their grease disposal methods. The inspection is documented and reports are prepared for other establishments. The inspector continues to travel to each establishment until all planned visits are complete or it is the end of the day. The inspector then drives back to the yard and submits all paperwork to the foreman.

4.4.3 SERVICE LINE RODDING/TELEVISING (SLR)

This activity involves the City responding to complaints of backed up drains in residents' houses. The crew is made up of one Drainage System Serviceman and one Labourer I/II. It requires working in basements, often in congested workspace, and hauling of equipment up and down stairs. The service line is cleared of any blockage using a series of interchangeable cables with a cutter on the end using a machine. The line is also televised to determine the cause of the blockages. The crew will also respond to broken MH/CB covers, CB face cleaning, and other complaints as necessary. Figure 39 displays a worker performing the SLR activity. The service televising camera is shown in the inset.

Figure 39: Example of SLR activity performed at an undisclosed location; camera (inset)

4.4.4 DESCRIPTION OF SLR ACTIVITY

The activity is divided into three major tasks: (1) work preparation, (2) SLR work steps, and (3) work completion.

1. *Work Preparation* – At this time, the foreman briefs the 2-person crew on the situation and assigns them a residential address (or addresses) to visit. A thorough vehicle check is performed to ensure that the vehicle is safe and functional to operate and that all equipment and materials necessary to perform the activity are present. After putting on personal protective equipment, the crew travels to the first location.
2. *SLR Work Steps* – Before the crew can contact the customer, adjacent sewer mainlines are inspected to rule out the possibility of having a plugged main as the source of the complaint. Next, the crew greets the customer and asks a series of questions to possibly diagnose the nature of the problem. The cleanout (sewer entry in buildings) is then located and inspected to ensure that the problem is actually within the service line that runs from the house to the mainline sewer. If not, the problem may be an inside plumbing one where the crew is not responsible for. Therefore, they inform the customer of the situation and notify their foreman. The

foreman can then assign them another address to visit. Otherwise, if the problem is within the service line, the crew carries on by bringing in the necessary equipment and tools to the workspace. The sewage service line is rodded by the operator using a machine that inserts and rotates a snake-like piece of equipment with an interchangeable cutting end into the line. This action is done until either an obstruction occurs or the mainline has been reached. The blockage should be released at this point. After removal of the snake by both the operator and labourer, a specialized camera is inserted to inspect the line for possible structural defects (collapsed pipe, cracks, misaligned pipe) and physical obstructions (roots, grease, etc.). This is recorded and documented at various distances along the service pipe. The workspace is then cleaned up and their equipment and tools are removed and stored in their truck. The customer is notified of the work done and of any necessary steps to act upon as a result of the problem. After all work has been completed at the location, the foreman is called to assign the crew a new location to repeat the work conducted. Otherwise, the crew returns back to the yard.

3. *Work Completion* – Upon arrival at the yard, the crew cleans, inspects, and stores all equipment used during the shift. All paperwork is then completed and submitted to the foreman.

4.4.5 CATCH BASIN CLEANING (CBC)

The activity involves a crew of two: Equipment Operator III and Labourer I/II. The cleaning of these catch basins is conducted along bus routes and freeways assigned by their foreman (normally an area of the city is assigned). The crew will also respond to emergencies as necessary. Figure 40 shows workers engaged in the CBC activity.

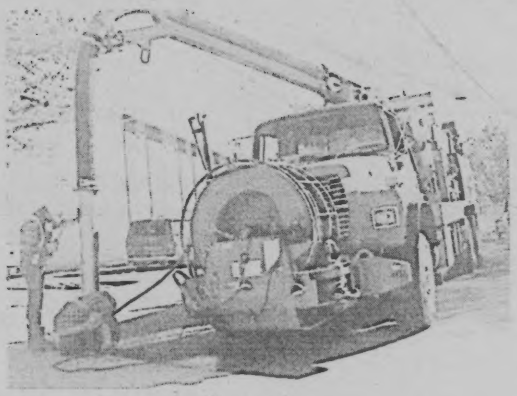


Figure 40: Example of cleaning a catch basin with vacuum

4.4.6 DESCRIPTION OF CBC ACTIVITY

The activity is divided into three major tasks: (1) work preparation, (2) CBC work steps, and (3) work completion.

1. *Work Preparation* – After consulting a map to confirm the 2-person crew's route to clean the catch basins within their assigned area, a thorough vehicle check is performed to ensure that the vehicle is safe and functional to operate and that all equipment and materials necessary to perform the activity are present. After putting on personal protective equipment, the crew travels to the first location.
2. *CBC Work Steps* – Once arriving at the worksite, the truck is parked and traffic control devices are setup. The catch basin (CB) is then opened and marked (to physically indicate work completion). The various vacuum pipe segments are assembled and attached to the truck unit. The operator lowers the vacuum into the CB where debris cleaned out. Depending on how dirty the CB is, the labourer washes the inside of the CB while the vacuum is turned on. Sometimes, a stick puller is used to remove any debris such as twigs that the vacuum could not remove. Next, the vacuum pipe is raised out of the CB and the CB is closed. All traffic control devices are stored and the crew travels to the next location to repeat the process. Work carries on until the debris tank of the truck unit is full and the

debris is discarded at a designated area of the operations yard. In some instances, traveling to the yard from a distant work location to dump the accumulated debris is not warranted. Therefore, the debris water is dumped into the mainline to free some space in the debris tank. Also, if the water tank needs filling, the truck is filled at a near by hydrant. If not, the truck is filled at the operations yard.

3. *Work Completion* – Upon arrival at the yard, the crew cleans, inspects, and stores all equipment used during the shift. All paperwork is completed and then submitted to the foreman.

4.4.7 HIGH PRESSURE FLUSHING (HPF)

This activity involves a crew of two: Equipment Operator III and Labourer I/II. The objective is to run a high pressure flushing hose and nozzle repeatedly through a mainline from a predetermined manhole to the next upstream (or downstream) manhole and back, until the mainline is clean and free of any debris or grease build-up. The crew will also respond to emergencies as necessary. Figure 41 displays crewmembers engaged in the HPF activity.

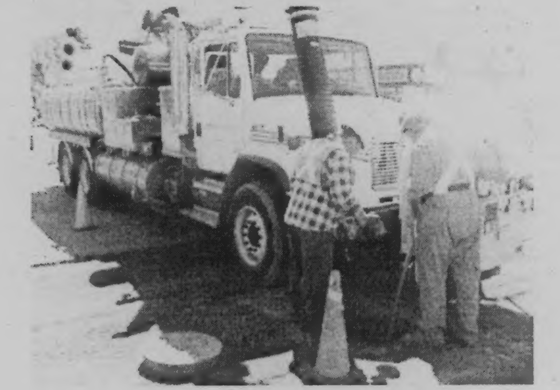


Figure 41: Example of HPF activity at upstream manhole

4.4.8 DESCRIPTION OF HPF ACTIVITY

The activity is divided into three major tasks: (1) work preparation, (2) HPF work steps, and (3) work completion.

1. *Work Preparation* – At this time, the foreman briefs the 2-person crew on the situation and assigns them a street address of where the drainage problem is or could potentially occur. A thorough vehicle check is performed to ensure that the vehicle is safe and functional to operate and that all equipment and materials necessary to perform the activity are present. After putting on personal protective equipment, the crew travels to the first location.
2. *HPF Work Steps* – There are two parts to the process: (a) water tank filling and (b) mainline high pressure flushing.
    a. Whenever necessary, the water tank of the truck must be filled up. The crew arrives at the hydrant, park the truck, and setup all necessary traffic control devices. The labourer opens the valve on the hydrant and lets the "dirty" water run (flushing) until the water becomes clear while the operator unloads the hose from the truck. After flushing for a few seconds, the labourer attaches the hose to the hydrant and opens the valve to fill up the truck's water tank. When full, the labourer closes the hydrant and closes the valve while the operator stores the hose. The operator then completes a hydrant use report.

    b. Once arriving at the worksite, the truck is parked and traffic control devices are setup. Each work location consists of a number of mainline stretches between manholes. The crew moves to each manhole, opens and inspects it for condition and debris, and they remove any sticks and other debris nearby. The nozzle is connected to the hose, lowered into the manhole, and placed into the upstream mainline {the sleeve is lowered and positioned – check video}. The line is then flushed in the direction of the next upstream manhole. The hose is moved up the mainline approximately 18 meters and rewound back to the manhole lead. This step is repeated, extending the nozzle approximately 6 meters farther up the mainline each time until the upstream manhole is reached. Whenever necessary, the vacuum is activated to remove the heavy debris that accumulates from flushing the mainline. The vacuum equipment is used at anytime during the flushing operation. The vacuum pipe is assembled and lowered into the manhole. The pipe is then attached to the vacuum unit and activated. When the flushing water running to the downstream manhole is clear and there is no sign of debris at both the upstream and downstream manholes, the current stretch is clean. The vacuum pipe is raised out of the downstream manhole and disassembled. The hose is rewound and all equipment is stored. The manhole is closed and all traffic control devices are stored. At any time the debris tank is full, the debris water can be emptied at the manhole (or adjacent mainline). Any relevant paper work is completed after every mainline cleaned.

3. *Work Completion* – (No data recorded – collected data did not include work completion steps, however, the same steps would have applied otherwise) When arriving at the yard, the crew cleans, inspects, and stores all equipment used during the shift. All paperwork is then submitted to the foreman.

4.5 SIMULATION APPLICATION FOR CURRENT CREWS' SITUATION

As in the MTV example, the same process is conducted on the four remaining crews. Figures 42 through 50 show the simulation models depicting current work methods for the four remaining crews developed using the common template described in Section 2.4.2. Figures 42 and 43 display the current work method for CEI, Figures 44, 45, and 46 present the current SLR work method, Figures 47 and 48 represent the present scheme for CBC, and Figures 49 and 50 illustrate the existing process for HPF. Any differences from actual and simulated results could be attributable to delay elements not simulated and not being able to capture every scenario that could take place anytime during the shift. The outputs of the simulation models are summarized in Table 15.

Table 15: Current simulation output for remaining crews

CREW	*MEAN*	*LOW*	*HIGH*	*UNITS*
CEI	**13.93**	11.00	19.00	locations (or sites/day)
SLR	**3.76**	3.00	5.00	locations (or sites/day)
CBC	**42.52**	15.00	54.00	locations (or sites/day)
HPF	**580.73**	257.61	985.95	locations (or sites/day)

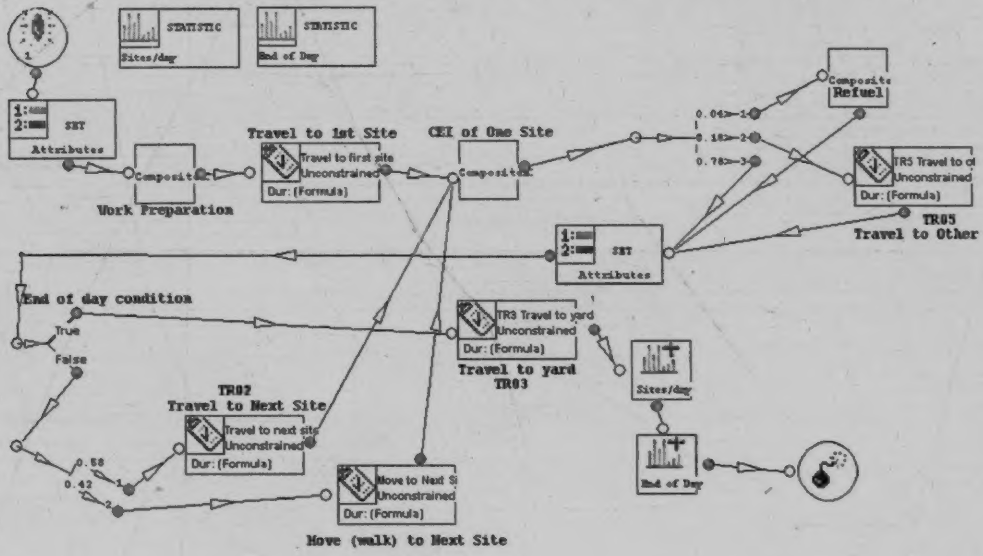

STATISTIC
Sites/day
STATISTIC
End of Day
SET
Attributes
Composite
Work Preparation
Travel to 1st Site
Travel to first site
Unconstrained
Dur: (Formula)
CEI of One Site
Composite
0.04
0.18
0.78
Composite
Refuel
TR5 Travel to ot
Unconstrained
Dur: (Formula)
TR05
Travel to Other
SET
Attributes
End of day condition
True
False
TR3 Travel to yard
Unconstrained
Dur: (Formula)
Travel to yard
TR03
Sites/day
End of Day
TR02
Travel to Next Site
Travel to next site
Unconstrained
Dur: (Formula)
0.58
0.42
Move to Next Si
Unconstrained
Dur: (Formula)
Move (walk) to Next Site

Figure 42: Current CEI general purpose simulation parent window

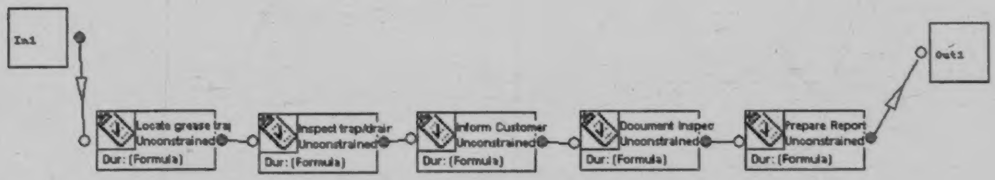

In1
Locate grease tra
Unconstrained
Dur: (Formula)
Inspect trap/drair
Unconstrained
Dur: (Formula)
Inform Customer
Unconstrained
Dur: (Formula)
Document Inspec
Unconstrained
Dur: (Formula)
Prepare Report
Unconstrained
Dur: (Formula)
Out1

Figure 43: Current CEI general purpose simulation child window "CEI of One Site"

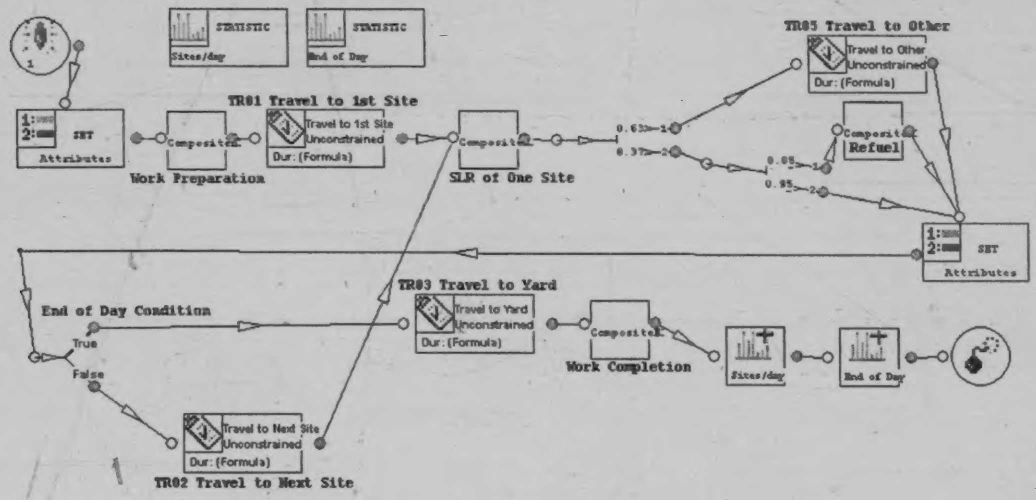

STATISTIC
Sites/day
STATISTIC
End of Day
TR05 Travel to Other
Travel to Other
Unconstrained
Dur: (Formula)
TR01 Travel to 1st Site
SET
Attributes
Composite
Travel to 1st Site
Unconstrained
Dur: (Formula)
Composite
0.63
0.37
0.05
0.95
Composite
Refuel
Work Preparation
SLR of One Site
SET
Attributes
TR03 Travel to Yard
End of Day Condition
True
False
Travel to Yard
Unconstrained
Dur: (Formula)
Composite
Work Completion
Sites/day
End of Day
Travel to Next Site
Unconstrained
Dur: (Formula)
TR02 Travel to Next Site

Figure 44: Current SLR general purpose simulation parent window

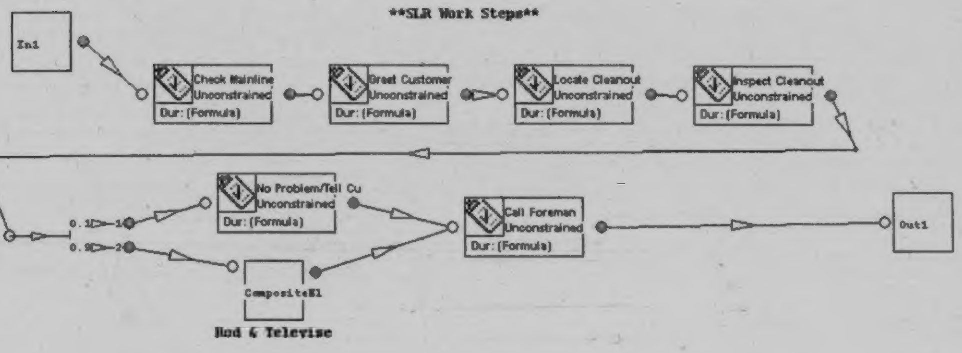

SLR Work Steps
In1
Check Mainline
Unconstrained
Dur: (Formula)
Greet Customer
Unconstrained
Dur: (Formula)
Locate Cleanout
Unconstrained
Dur: (Formula)
Inspect Cleanout
Unconstrained
Dur: (Formula)
No Problem/Tell Cu
Unconstrained
Dur: (Formula)
0.1
0.9
Call Foreman
Unconstrained
Dur: (Formula)
Out1
CompositeE1
Rod & Televise

Figure 45: Current SLR general purpose simulation child window of "SLR of One Site"

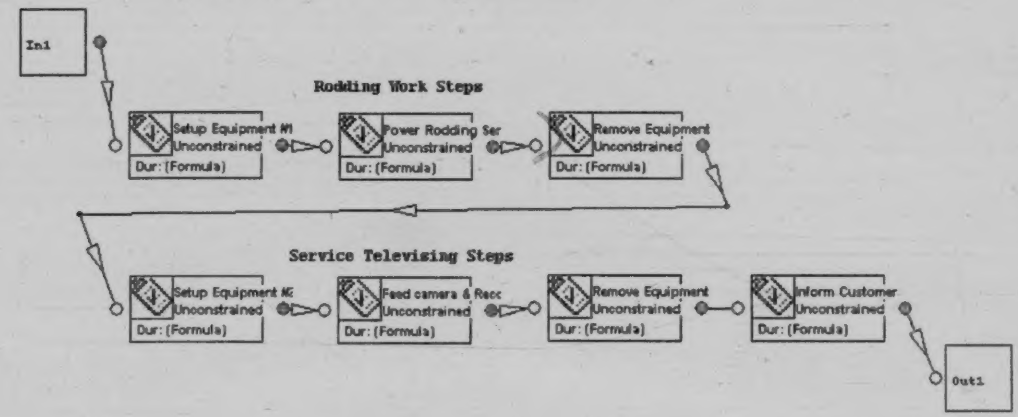

In1
Rodding Work Steps
Setup Equipment #1
Unconstrained
Dur: (Formula)
Power Rodding Ser
Unconstrained
Dur: (Formula)
Remove Equipment
Unconstrained
Dur: (Formula)
Service Televising Steps
Setup Equipment #2
Unconstrained
Dur: (Formula)
Feed camera & Recc
Unconstrained
Dur: (Formula)
Remove Equipment
Unconstrained
Dur: (Formula)
Inform Customer
Unconstrained
Dur: (Formula)
Out1

Figure 46: Current SLR general purpose simulation child window of "Rod & Televise"

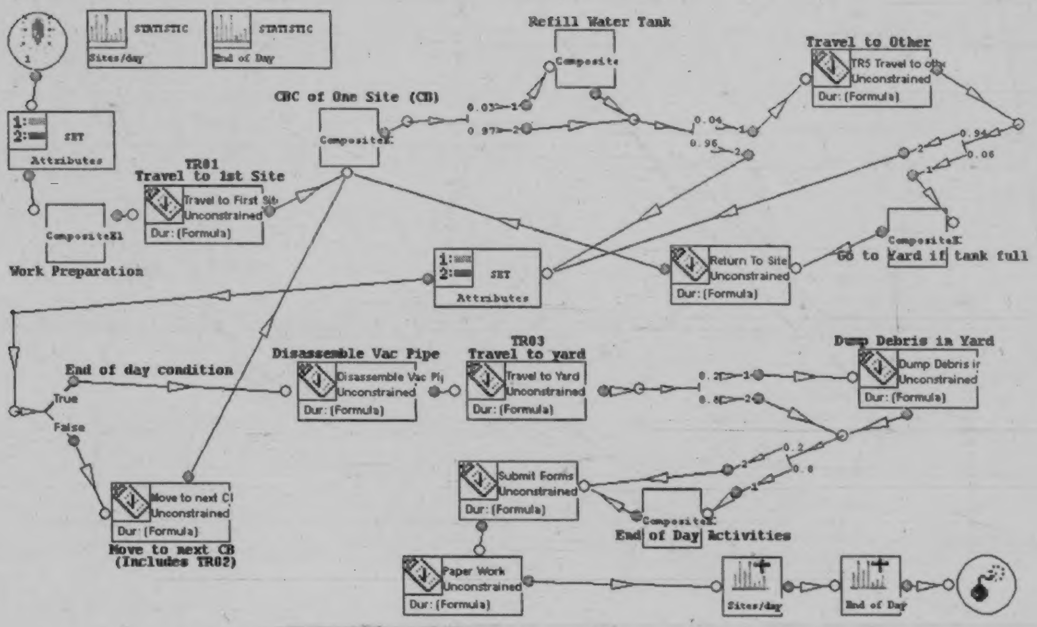

STATISTIC
Sites/day
STATISTIC
End of Day
SET
Attributes
Refill Water Tank
Composite
Travel to Other
TR5 Travel to other
Unconstrained
Dur: (Formula)
CBC of One Site (CB)
CompositeX
0.03
0.97
0.04
0.96
0.94
0.06
TR01
Travel to 1st Site
Travel to First Site
Unconstrained
Dur: (Formula)
CompositeX1
Work Preparation
SET
Attributes
Return To Site
Unconstrained
Dur: (Formula)
CompositeX
Go to Yard if tank full
End of day condition
True
False
Disassemble Vac Pipe
Disassemble Vac Pipe
Unconstrained
Dur: (Formula)
TR03
Travel to yard
Travel to Yard
Unconstrained
Dur: (Formula)
0.2
0.8
Dump Debris in Yard
Dump Debris in
Unconstrained
Dur: (Formula)
Move to next CB
Unconstrained
Dur: (Formula)
Move to next CB
(Includes TR02)
Submit Forms
Unconstrained
Dur: (Formula)
0.2
0.8
CompositeX
End of Day Activities
Paper Work
Unconstrained
Dur: (Formula)
Sites/day
End of Day

Figure 47: Current CBC general purpose simulation parent window

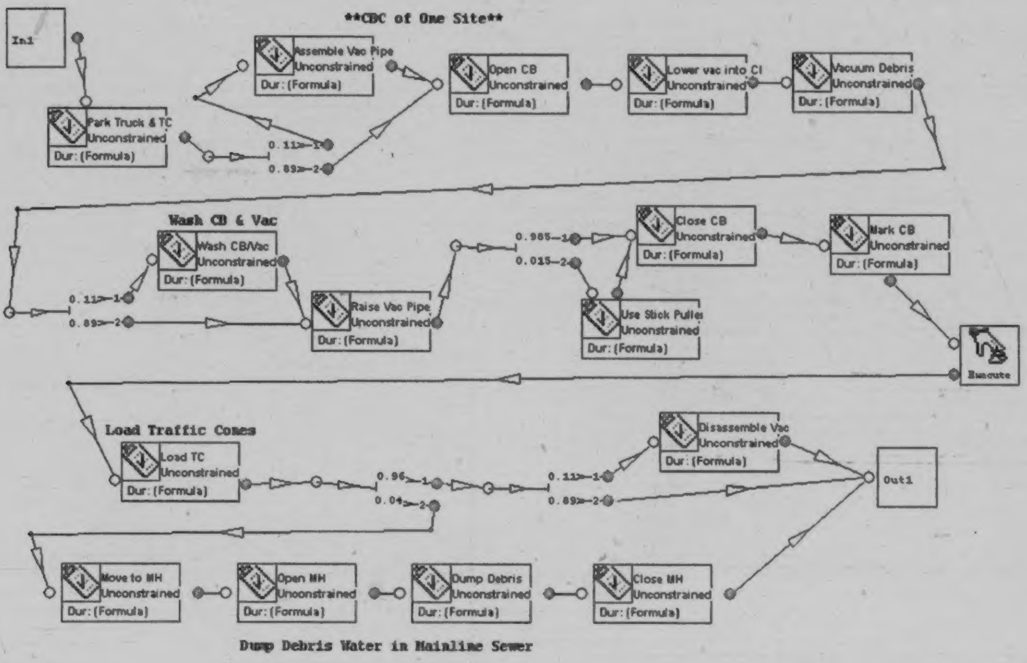

In1
CBC of One Site
Park Truck & TC
Unconstrained
Dur: (Formula)
Assemble Vac Pipe
Unconstrained
Dur: (Formula)
0.11
0.89
Open CB
Unconstrained
Dur: (Formula)
Lower vac into CB
Unconstrained
Dur: (Formula)
Vacuum Debris
Unconstrained
Dur: (Formula)
Wash CB & Vac
Wash CB/Vac
Unconstrained
Dur: (Formula)
0.11
0.89
Raise Vac Pipe
Unconstrained
Dur: (Formula)
0.985
0.015
Close CB
Unconstrained
Dur: (Formula)
Use Stick Puller
Unconstrained
Dur: (Formula)
Mark CB
Unconstrained
Dur: (Formula)
Execute
Load Traffic Cones
Load TC
Unconstrained
Dur: (Formula)
0.96
0.04
0.11
0.89
Disassemble Vac
Unconstrained
Dur: (Formula)
Out1
Move to MH
Unconstrained
Dur: (Formula)
Open MH
Unconstrained
Dur: (Formula)
Dump Debris
Unconstrained
Dur: (Formula)
Close MH
Unconstrained
Dur: (Formula)
Dump Debris Water in Mainline Sewer

Figure 48: Current CBC general purpose simulation child window of "CBC of One Site"

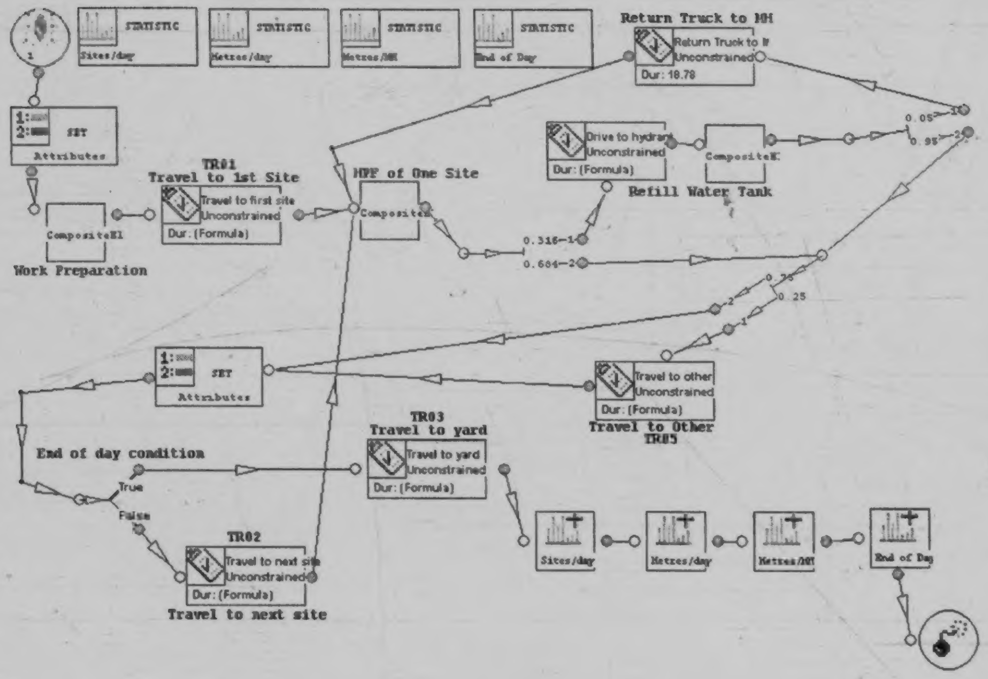

STATISTIC
Sites/day
STATISTIC
Metres/day
STATISTIC
Metres/MH
STATISTIC
End of Day
Return Truck to MH
Return Truck to M
Unconstrained
Dur: 18.78
1:
2:
SET
Attributes
TR01
Travel to 1st Site
Travel to first site
Unconstrained
Dur: (Formula)
HPF of One Site
Composite
Drive to hydrant
Unconstrained
Dur: (Formula)
CompositeE
Refill Water Tank
0.05
0.95
CompositeE1
Work Preparation
0.316–1
0.684–2
0.75
0.25
SET
Attributes
Travel to other
Unconstrained
Dur: (Formula)
Travel to Other
TR05
TR03
Travel to yard
Travel to yard
Unconstrained
Dur: (Formula)
End of day condition
True
False
TR02
Travel to next site
Unconstrained
Dur: (Formula)
Travel to next site
Sites/day
Metres/day
Metres/MH
End of Day

Figure 49: Current HPF general purpose simulation parent window

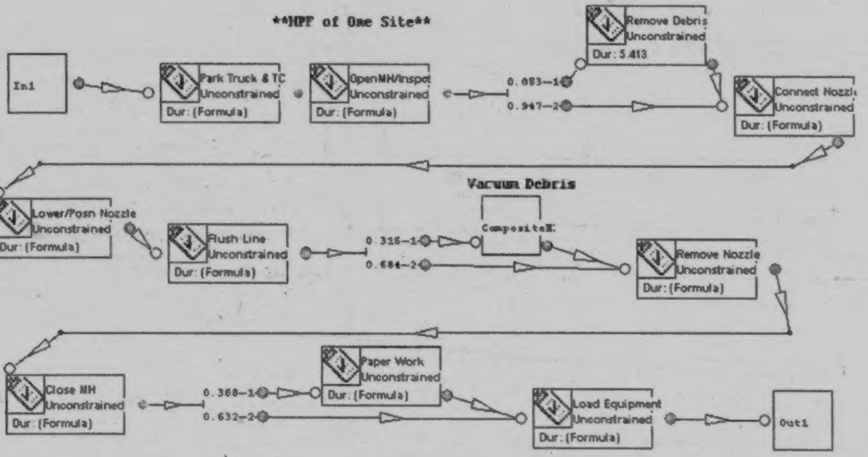

HPF of One Site
In1
Park Truck & TC
Unconstrained
Dur: (Formula)
OpenMH/Inspect
Unconstrained
Dur: (Formula)
0.053–1
0.947–2
Remove Debris
Unconstrained
Dur: 5.413
Connect Nozzle
Unconstrained
Dur: (Formula)
Lower/Posn Nozzle
Unconstrained
Dur: (Formula)
Flush Line
Unconstrained
Dur: (Formula)
0.316–1
0.684–2
Vacuum Debris
CompositeE
Remove Nozzle
Unconstrained
Dur: (Formula)
Close MH
Unconstrained
Dur: (Formula)
0.368–1
0.632–2
Paper Work
Unconstrained
Dur: (Formula)
Load Equipment
Unconstrained
Dur: (Formula)
Out1

Figure 50: Current HPF general purpose simulation child window of "HPF of One Site"

4.5 LEAN-THINKING APPLICATION

Each crew has been evaluated for work method improvement similar to that used for the MTV crews (see Section 4.3.3) and are summarized in this section. Figure 51 displays the percentage of VA and NVA elements per crew, Figure 52 presents the breakdown of NVA process steps, whereas Figure 53 shows the breakdown of the delay elements for each crew. Tables 16, 17, 18, and 19 display the process steps broken down as well as the identification of VA and NVA elements for each crew.

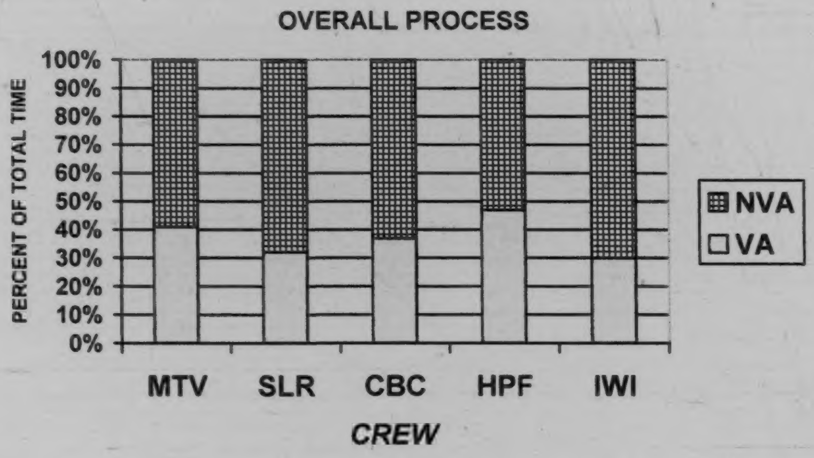


Figure 51: Overall VA vs. NVA per crew

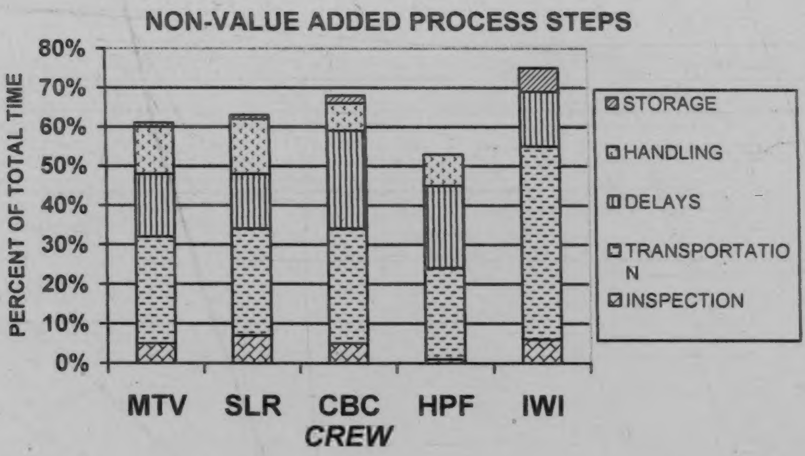


Figure 52: Breakdown of NVA process steps for each crew

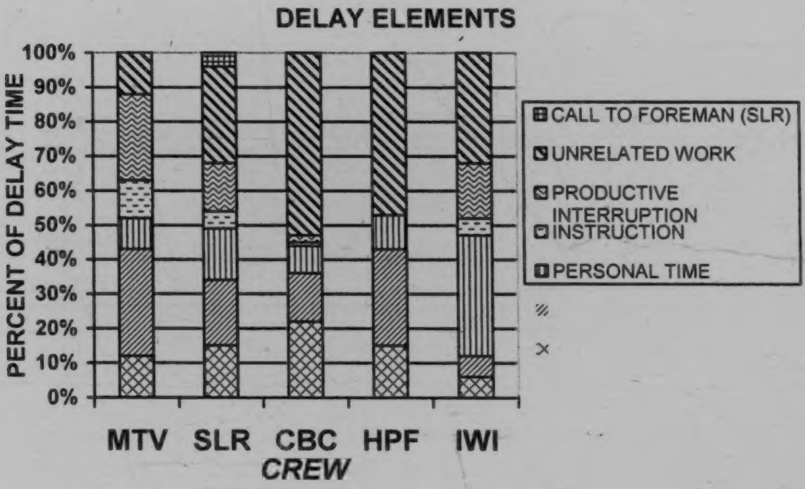


Figure 53: Breakdown of NVA delay elements for each crew

Table 16: Element breakdown (CEI) and VA/NVA identification

Element	*Process Step Cycle Time*[1]	*Normal Time (x frequency)*	*Process Step*	*Symbol*	*VA/NVA*
Work Preparation					
Determine Zones	28.26	4.42(x6.4)	Operation	●	VA
Vehicle Check	4.32	0.80(x5.4)	Inspection	■	NVA
Work Steps					
Locate Grease Trap	19.40	1.59(x12.2)	Inspection	■	NVA
Inspect Trap/Drain	35.08	2.92(x12)	Operation	▣	VA
Inform Customer	11.16	0.95(x11.8)	Operation	●	VA
Document Inspection	4.78	0.43(x11.2)	Operation	●	VA
Prepare Reports	31.21	2.64(x11.8)	Operation	●	VA
Move to Next Site	7.56	1.80(x4.2)	Transportation	→	NVA
Travel Times and Refuelling					
Travel to 1st site	33.88	33.88(x1)	Transportation	→	NVA
Travel to Next Site	86.36	10.53(x8.2)	Transportation	→	NVA
Travel to Yard	36.77	30.64(x1.2)	Transportation	→	NVA
Travel to Gas Station	1.74	4.34(x0.4)	Transportation	→	NVA
Travel to Other	18.71	10.40(x1.80)	Transportation	→	NVA
Refuel	1.80	4.51(x0.4)	Operation	●	VA
Delays (Lost Time and Productive Foreign Elements)					
Lost Time					
Idle Time	3.28		Delay	◗	NVA
Excessive Work	3.29		Delay or Rework	◗ Ⓡ	NVA
Personal Time	18.64		Delay	◗	NVA
Instruction	2.79		Delay	◗	NVA
Productive Foreign Elements					
Productive Interruption	8.38		Delay	◗	NVA
Unrelated Work	16.16		Delay	◗	NVA

Note: 1. Accumulated amount over entire shift. E.g. "Inspect Trap/Drain". Normal time = total raw time/#obs=175.16/60=2.92 minutes
Process step cycle time for "Record Main Inspection"=(normal time)*(frequency)=(2.92)*(12)=35.08 minutes

Table 17: Element breakdown (SLR) and VA/NVA identification

Element	*Process Step Cycle Time*	*Normal Time (xfrequency)*	*Process Step*	*Symbol*	*VA/NVA*
Work Preparation					
Get Instructions	8.21	7.14(x1.15)	Operation	●	VA
Vehicle Inspection	8.34	8.97(x0.93)	Inspection	■	NVA
Work Steps					
Check Mainline	5.23	2.71(x1.93)	Inspection	■	NVA
Greet Customer	8.68	2.52(x3.44)	Operation	●	VA
Locate Cleanout	8.26	2.62(x3.15)	Inspection	■	NVA
Inspect Cleanout	12.16	4.33(x2.81)	Inspection	■	NVA
No Problem/Tell Customer	0.81	2.46(x0.33)	Operation	●	VA
Setup Equipment #1 (Rod)	16.85	7.99(x2.11)	Handling	➡	NVA
Power Rodding Service Line	54.64	25.90(x2.11)	Operation	●	VA
Remove Equipment #1	22.61	11.31(x2.00)	Handling	➡	NVA
Setup Equipment #2 (TV)	10.49	4.30(x2.44)	Handling	➡	NVA
Feed Camera & Record	29.07	11.35(2.56)	Operation	●	VA
Remove Equipment #2	18.94	7.99(x2.37)	Handling	➡	NVA
Inform Customer/Problem	17.06	5.61(x3.04)	Operation	●	VA
Work Completion					
Inspect Equipment	3.01	3.72(x0.81)	Inspection	■	NVA
Clean Equipment	21.57	12.12(x1.78)	Operation	●	VA
Store Equipment	2.70	2.35(x1.15)	Storage	▼	NVA
Paper Work	41.34	9.96(x9.96)	Operation	●	VA
Submit Forms	2.00	2.25(x0.89)	Operation	●	VA
Travel Times and Refuelling					
Travel to 1st site	27.35	27.35(x1.00)	Transportation	→	NVA
Travel to Next Site	52.62	20.56(x2.56)	Transportation	→	NVA
Travel to Yard	28.75	18.91(x1.52)	Transportation	→	NVA
Travel to Gas Station	1.32	6.96(x0.19)	Transportation	→	NVA
Travel to Other	21.74	10.30(x2.11)	Transportation	→	NVA
Refuel	1.35	6.11(x0.22)	Operation	●	VA
Return To Site	0.24	5.39(x0.07)	Transportation	→	NVA
Delays (Lost Time and Productive Foreign Elements)					
Lost Time					
Idle Time	10.42		Delay	◗	NVA
Excessive Work	13.42		Delay or Rework	◗ Ⓡ	NVA
Personal Time	10.45		Delay	◗	NVA
Instruction	3.50		Delay	◗	NVA
Productive Foreign Elements					
Productive Interruption	9.43		Delay	◗	NVA
Unrelated Work	19.82		Delay	◗	NVA
Call to Foreman	2.58		Delay	◗	NVA

Note: 1. Accumulated amount over entire shift. E.g. "Power Rodding Service Line". Normal time = total raw time/#obs=1476/57=25.896 minutes Process step cycle time for "Power Rodding Service Line"=(normal time)*(frequency)=(25.896)*(2.11)=54.64 minutes

Table 18: Element breakdown (CBC) and VA/NVA identification

Element	*Process Step Cycle Time*[1]	*Normal Time (xfrequency)*	*Process Step*	*Symbol*	*VA/NVA*
Work Preparation					
Get Instructions	11.01	11.01(x1.00)	Operation	●	VA
Vehicle Inspection	16.05	16.05(x1.00)	Inspection	■	NVA
Work Steps					
Park Truck & Traffic Control	11.68	0.47(x24.6)	Operation	●	VA
Assemble Vacuum Pipe	7.34	2.16(x3.4)	Handling	➤	NVA
Open CB	8.52	0.26(x32.2)	Operation	●	VA
Mark CB	3.96	0.17(x22.9)	Operation	●	VA
Lower Vacuum into CB	14.19	0.47(x30.1)	Handling	➤	NVA
Vacuum Debris	37.46	1.29(x29.1)	Operation	●	VA
Use Stick Puller	1.35	2.70(x0.5)	Operation	●	VA
Wash CB/Vacuum	6.29	1.97(x3.2)	Operation	●	VA
Raise Vacuum Pipe	7.14	0.25(x28.4)	Handling	➤	NVA
Disassemble Vacuum Pipe	5.34	1.62(x3.3)	Handling	➤	NVA
Close CB	6.28	0.20(x31.0)	Operation	●	VA
Load Traffic Cones	11.30	0.52(x21.6)	Storage	▼	NVA
Move to Next CB	42.43	1.39(x30.6)	Transportation	→	NVA
Move to MH	1.71	1.32(x1.3)	Transportation	→	NVA
Open MH	0.58	0.41(x1.4)	Operation	●	VA
Dump Debris Water	6.79	4.85(x1.4)	Operation	●	VA
Close MH	0.29	0.26(x1.1)	Operation	●	VA
Dump Debris in Yard	17.28	11.52(x1.5)	Operation	●	VA
Move to Garage/Hydrant	2.71	3.39(x0.8)	Transportation	→	NVA
Couple Hose/Tank	1.55	1.41(x1.1)	Handling	➤	NVA
Open Valve/Fill Tank	8.69	7.90(x1.1)	Operation	●	VA
Close Valve/Hydrant	0.56	0.51(x1.1)	Handling	➤	NVA
Work Completion					
Inspect Equipment	7.12	5.94(x1.2)	Inspection	■	NVA
Clean Equipment	16.67	10.42(x1.6)	Operation	●	VA
Store Equipment	0.79	0.72(x1.1)	Storage	▼	NVA
Paper Work	6.82	9.75(x0.7)	Operation	●	VA
Submit Forms	3.82	3.82(x1.0)	Operation	●	VA
Travel Times and Refuelling					
Travel to 1st site	23.30	23.30(x1.0)	Transportation	→	NVA
Travel to Next Site	10.11	20.23(x0.5)	Transportation	→	NVA
Travel to Yard	43.16	20.55(x2.1)	Transportation	→	NVA
Travel to Gas Station	1.34	2.24(x0.6)	Transportation	→	NVA
Travel to Other	18.41	13.15(x1.4)	Transportation	→	NVA
Refuel	15.83	19.79(x0.8)	Operation	●	VA
Return To Site	0.57	0.81(x0.7)	Transportation	→	NVA
Delays (Lost Time and Productive Foreign Elements)					
Lost Time					
Idle Time	26.78		Delay	D	NVA
Excessive Work	16.53		Delay or Rework	D ®	NVA
Personal Time	10.08		Delay	D	NVA
Instruction	1.69		Delay	D	NVA
Productive Foreign Elements					
Productive Interruption	2.65		Delay	D	NVA
Unrelated Work	64.60		Delay	D	NVA

Note: 1. Accumulated amount over entire shift. E.g. "Vacuum Debris". Normal time = total raw time/#obs=374.7/291=1.29 minutes
Process step cycle time for "Vacuum Debris"=(normal time)*(frequency)=(1.29)*(29.1)=37.46 minutes

Table 19: Element breakdown (HPF) and VA/NVA identification

Element	*Process Step Cycle Time*[1]	*Normal Time (xfrequency)*	*Process Step*	*Symbol*	*VA/NVA*
Work Preparation					
Get Instructions	4.88	4.88(x1.0)	Operation	●	VA
Vehicle Inspection	6.99	6.99(x0.75)	Inspection	■	NVA
Water Tank Filling					
Drive to Hydrant/Yard	15.47	10.28(x1.5)	Transportation	→	NVA
Park Truck/Traffic	0.21	0.28(x0.75)	Operation	●	VA
Open Valve/Flush	0.79	1.05(x0.75)	Operation	●	VA
Close Valve/Hydrant	0.11	0.14(x0.75)	Handling	➡	NVA
Unload Hose	0.17	0.23(x0.75)	Handling	➡	NVA
Couple Hose/Tank	0.50	0.66(x0.75)	Handling	➡	NVA
Open Valve/Fill Tank	19.02	10.87(x1.75)	Operation	●	VA
"Hydrant Use" Report	0.93	1.87(x0.5)	Operation	●	VA
Close Valve/Hydrant	0.76	1.02(x0.75)	Handling	➡	NVA
Remove/Load Hose	0.67	0.89(x0.75)	Handling	➡	NVA
Work Steps					
Park truck/traffic	7.12	1.36(x5.25)	Operation	●	VA
Open/Inspect MH	3.19	0.64(x5.0)	Operation	●	VA
Remove Debris	1.35	5.41(x0.25)	Operation	●	VA
Connect Nozzle	1.70	1.13(x1.5)	Handling	➡	NVA
Lower/Position Nozzle	7.27	1.71(x4.25)	Handling	➡	NVA
Flush Line	89.06	20.95(x4.25)	Operation	●	VA
Remove Nozzle	2.67	1.18(x2.25)	Handling	➡	NVA
Activate Vacuum	0.33	0.22(x1.5)	Operation	●	VA
Assemble Vacuum Pipe	3.78	2.52(x1.5)	Handling	➡	NVA
Lower/Position Vacuum	1.26	0.84(x1.5)	Handling	➡	NVA
Vacuum Debris	31.98	21.32(x1.5)	Operation	●	VA
Raise & Disassemble	3.98	2.65(x1.5)	Handling	➡	NVA
Clean/Load Equipment	7.92	1.58(x5.0)	Handling	➡	NVA
Close MH	2.88	0.58(x5.0)	Operation	●	VA
Paper Work	5.03	2.87(x1.75)	Operation	●	VA
Move Truck	2.57	10.30(x0.250	Transportation	→	NVA
Dump Debris Water	7.53	15.06(x0.5)	Operation	●	VA
Return Truck to MH	4.70	18.78(x0.25)	Transportation	→	NVA
Travel Times and Refuelling					
Travel to 1st site	14.23	14.23(x1.0)	Transportation	→	NVA
Travel to Next Site	28.68	7.17(x4.0)	Transportation	→	NVA
Travel to Yard	9.60	9.60(x1.0)	Transportation	→	NVA
Travel to Gas Station	0.00	0.00(x0.0)	Transportation	→	NVA
Travel to Other	10.31	8.25(x1.25)	Transportation	→	NVA
Refuel	1.42	5.67(x0.25)	Operation	●	VA
Delays (Lost Time and Productive Foreign Elements)					
Lost Time					
Idle Time	12.13		Delay	◗	NVA
Excessive Work	22.15		Delay or Rework	◗ ®	NVA
Personal Time	8.20		Delay	◗	NVA
Instruction	0.00		Delay	◗	NVA
Productive Foreign Elements					
Productive Interruption	0.00		Delay	◗	NVA
Unrelated Work	35.89		Delay	◗	NVA

Note: 1. Accumulated amount over entire shift. E.g. "Flush Line". Normal time = total raw time/#obs=356.2/17=20.95 minutes
Process step cycle time for "Flush Line"=(normal time)*(frequency)=(20.95)*(4.25)=89.06 minutes

Developing suggestions to improve performance of the crews require the input, support, and consultation with training personnel, the crewmembers, management, and OH & S. However, these improvement ideas have only been discussed with the Office of the City Auditor and are used solely for the purpose of illustrating the potential gains in productivity subsequent to implementation. In certain instances, there may be saturation of the existing work method and hence, only technological advancements may be the only possible means of improving the cycle time of a process step and therefore improving the productivity of a crew. In most other cases, slight changes to the process combined with technological advancements are the keys to gaining enhancement in the crews' productivities. Table 20 summarizes the suggestions made to each work method, the benefits they provide, and whether implementation using simulation was conducted in the study. Although reduction in travel times have not been implemented in the simulation models, it will be assumed that the results of the study would likely improve in addition to the productivity gains. In an additional analysis conducted, further recommendations to improve the work methods of the drainage crews were documented and can be found in Appendix A.

Table 20: Lean concepts summary of suggested modifications to CEI, SLR, CBC, and HPF crews

CREW	SUGGESTION	BENEFIT	SIMULATED IN STUDY (Yes/No)
CEI	100% saturation of work method – introduce tool belt and electric tool (screwdriver)	Reduces "inspect trap/drain" cycle time. Increases ergonomic comfort, decreases strain from repetitive motions of opening/closing traps and drains.	Yes. *(see Note 4)
	Organization-wide improved labour tracking system (see Section 4.10.2 for details)	Improves information flow, reduces "Paper Work" completion times (includes timesheets and other documentation), reduces paper	No, because no "Paper Work" or "Submit Forms" data collected at this time. *(see Notes 1, 2, and 5) Yes. *(see Note 2)
	Vehicle Routing Optimization System (see Section 4.10.1 for details)	Reduces travel times	No. *(see Notes 1, 3, and 5)
SLR	Labourer can "Check Mainline" while serviceman "Greets Customer"	Improved worker deployment	Yes
	Combine "Locate Cleanout" and "Inspect Cleanout"	Improved worker deployment	Yes
	Labourer "Removes Equip#2" while serviceman "Informs Customer of Problem"	Improved worker deployment	Yes
	Organization-wide improved labour tracking system (see Section 4.10.2 for details)	Improves information flow, reduces "Paper Work" completion times (includes timesheets and other documentation), reduces paper	No. *(see Notes 1, 2 and 5) Yes. *(see Note 4)
	Vehicle Routing Optimization System (see Section 4.10.1 for details)	Reduces travel times	No. *(see Notes 1, 3, and 5)
CBC	Eliminate "Mark CB"	Process step can be performed at anytime such as during "Vacuum debris"	Yes
	Organization-wide improved labour tracking system (see Section 4.10.2 for details)	Improves information flow, reduces "Paper Work" completion times (includes timesheets and other documentation), reduces paper	No. *(see Notes 1, 2, and 5) Yes. *(see Note 4)
	Vehicle Routing Optimization System (see Section 4.10.1 for details)	Reduces travel times	No. *(see Notes 1, 3, and 5)
HPF	Grappling pole or mainline sewer entrance lip (newly built sewer systems could adapt/wherever elevated entrances exist)	Enables easier insertion of nozzle into mainline – reduction in cycle time of "Lower/Position Nozzle"	Yes. *(see Note 4)
	Eliminate "Remove Debris"	Process step can be performed at anytime such as during "Flush Line"	Yes
	Organization-wide improved labour tracking system (see Section 4.10.2 for details)	Improves information flow, reduces "Paper Work" completion times (includes timesheets and other documentation), reduces paper	No. *(see Notes 1, 2, and 5) Yes. *(see Note 4)
	Vehicle Routing Optimization System (see Section 4.10.1 for details)	Reduces travel times	No. *(see Notes 1, 3, and 5)

**Note:*

1. A substantial amount of development and training will have to be provided to implement this type of system.
2. SAP, an enterprise resource planning (ERP), system currently under implementation.
3. SLIM vehicle routing system in planning stage.
4. Based on field observation and/or videotape, an educated guess for reduction in cycle time is assumed.
5. See Section 4.10 for details on future implementations.

4.7 INTEGRATING LEAN-THINKING AND SIMULATION

Figure 54 represents the suggestion for CEI (shown in Table 20) as implemented within the simulation model. Assuming a uniform distribution for the "Inspect Trap/Drain" element, the minimum and maximum times that were used during the simulation runs for the current work method were 0.37 and 6.49 minutes, respectively. The reduction of the cycle time for the "Inspect Trap/Drain" was based on an educated guess after observing the work during the data collection period and prior to that, several viewings of a videotaped recording of the inspection. Thus, by assuming a reduction of the maximum cycle time to perform the inspection to be 2.3 minutes, the productivity of the commercial establishment investigation increased to 16.24 sites per day, an improvement of 2.31 sites per day or 16.6 %. Figure 55 displays the difference in productivity gained before and after lean application. For instance, at a probability of 60%, the productivity is higher for the modified work method than the current work method. See Table 21 for a complete summary of results.

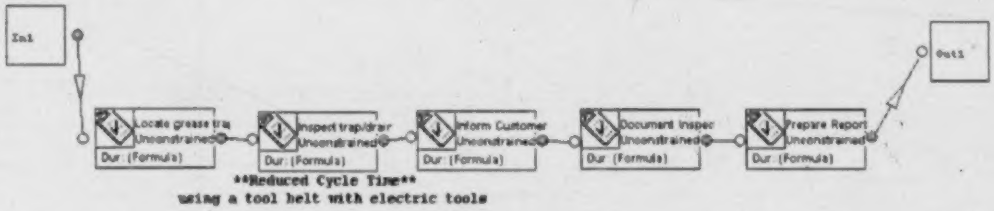

In1
Locate grease tra
Unconstrained
Dur: (Formula)
Inspect trap/drair
Unconstrained
Dur: (Formula)
Inform Customer
Unconstrained
Dur: (Formula)
Document Inspec
Unconstrained
Dur: (Formula)
Prepare Report
Unconstrained
Dur: (Formula)
Out1
Reduced Cycle Time
using a tool belt with electric tools

Figure 54: Modified CEI work method

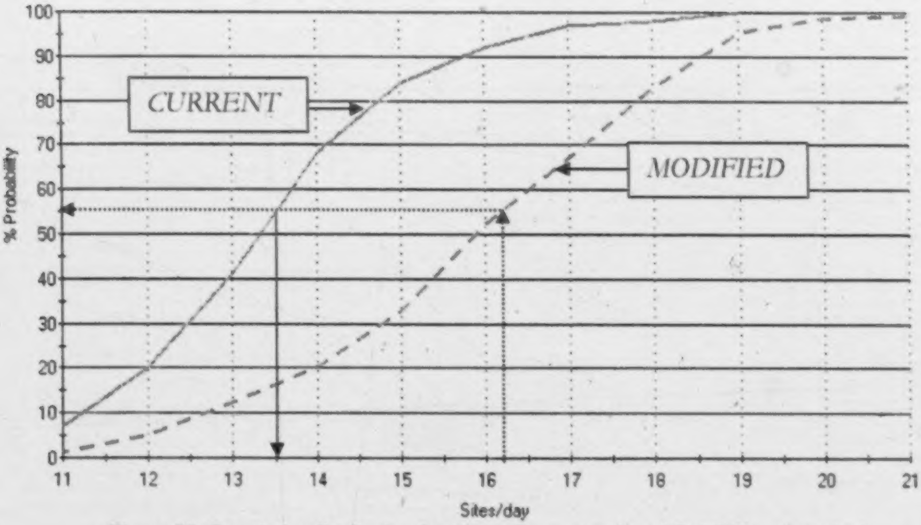
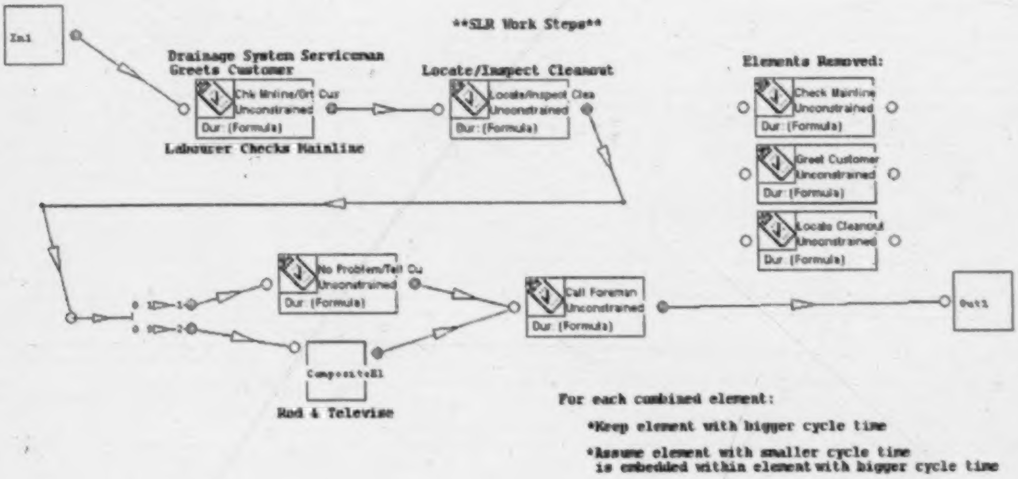


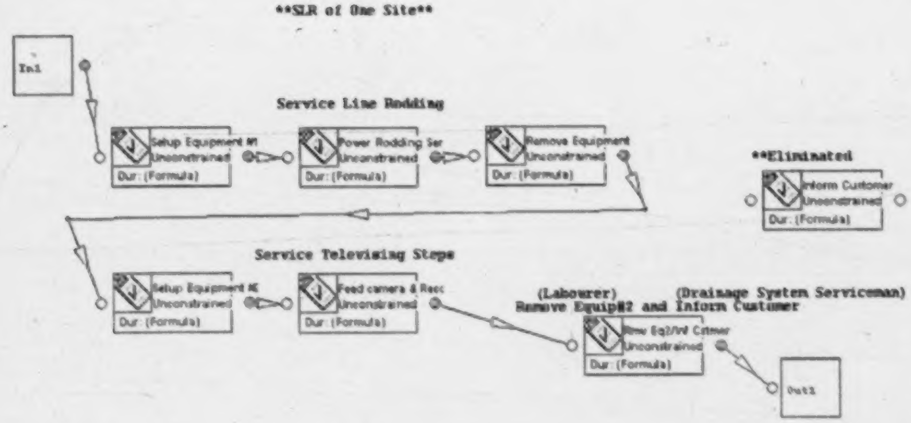
Figure 55: Cumulative distribution functions of current and modified CEI work method

Figures 56 and 57 display the SLR models as implemented using the suggestions from Table 20. To simplify the implementation process for SLR, the assumption that the smaller cycle time (5.23 minutes) of "Check Mainline" performed by the labourer occurs within the larger cycle time (8.68 minutes) of "Greet Customer" performed by the serviceman resulted in the formation of a work step that incorporates both elements. Consequently, the non-value added task "Check Mainline" has been eliminated in favour of the value-added "Greet Customer" task to create a "Check Mainline/Greet Customer" value-added element. As well, the smaller cycle time (17.06 minutes) of "Inform Customer/Problem" performed by the serviceman is assumed to occur within the larger cycle time (18.94 minutes) of "Remove Equipment #2" performed by the labourer resulted in the formation of a work step that accounts for both tasks. Again, the non-value added task "Remove Equipment #2" and value-added task "Inform Customer/Problem" combined to create the value-added "Remove Equipment #2/Inform Customer" element. In terms of introducing an automated labour tracking system, based on observing the crews during the data collection period, an educated guess of a 15-minute cycle time for the element "Paper Work" has been assumed. That is, the current uniform distribution (low – 0.63 minutes, high – 36.7 minutes) has been modified by assuming a smaller "high" value of 15 minutes. After implementing the changes as described, an increase from 3.76 to 4.16 sites per day yields an increase of 0.4 sites per day or 10.6 %. In addition, Figure 58 displays the difference in productivity gained before and after lean application. For instance, at a probability of 55%, the productivity is higher for the modified work method than the current work method. See Table 21 for complete summary of results.



SLR Work Steps
In1
Drainage System Serviceman Greets Customer
Chk Mnline/Grt Cus
Unconstrained
Dur: (Formula)
Labourer Checks Mainline
Locate/Inspect Cleanout
Locate/Inspect Clea
Unconstrained
Dur: (Formula)
Elements Removed:
Check Mainline
Unconstrained
Dur: (Formula)
Greet Customer
Unconstrained
Dur: (Formula)
Locate Cleanout
Unconstrained
Dur: (Formula)
No Problem/Tell Cu
Unconstrained
Dur: (Formula)
Call Foreman
Unconstrained
Dur: (Formula)
Out1
CompositeEl
Rod & Televise
For each combined element:
*Keep element with bigger cycle time
*Assume element with smaller cycle time is embedded within element with bigger cycle time

Figure 56: Modification of "SLR of One Site" work method



SLR of One Site
In1
Service Line Rodding
Setup Equipment #1
Unconstrained
Dur: (Formula)
Power Rodding Ser
Unconstrained
Dur: (Formula)
Remove Equipment
Unconstrained
Dur: (Formula)
**Eliminated
Inform Customer
Unconstrained
Dur: (Formula)
Service Televising Steps
Setup Equipment #2
Unconstrained
Dur: (Formula)
Feed camera & Rec
Unconstrained
Dur: (Formula)
(Labourer) (Drainage System Serviceman)
Remove Equip#2 and Inform Customer
Rmv Eq2/Inf Cstmer
Unconstrained
Dur: (Formula)
Out1

Figure 57: Modification of "Rod & Televise" work method

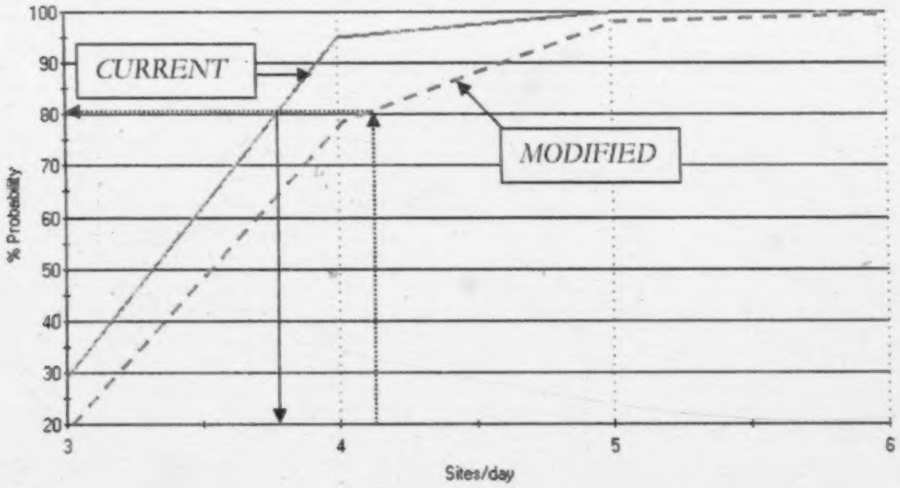


Figure 58: Cumulative distribution functions of current and modified SLR work method

The current CBC method demonstrates an almost saturation state, i.e. not many modifications to the work process are available. Figure 59 displays the CBC model with the adaptation of the suggestion stated in Table 20. The elimination of the "Mark CB" element works because it can be performed by the labourer at anytime during the cleaning of the CB and does not need to be modeled. Although it is a value-adding work step, based on observing the crews during the data collection period, it seems to be the only appropriate modification possible at this time. As a result, there will not be much difference in the ratio of non-value added to value-added tasks. In terms of the implementation of an organization-wide automated labour timesheet system, the data collected does not seem appropriate to implement lean theory within the simulation model because of the relatively short cycle time of the "Paper Work" task. It was not captured fully during the time study data collection period. After implementing the suggestions, the productivity is expected to improve from 42.52 sites per day to 44.25 sites per day. An increase of 1.73 sites per day or 4 % proves that an enhancement of productivity by lean-thinking, although small, is possible. Figure 60 displays the difference in productivity gained before and after lean application. For instance, at a probability of 80%, the productivity is higher for the modified work method than the current work method. See Table 21 for a complete summary of the results.

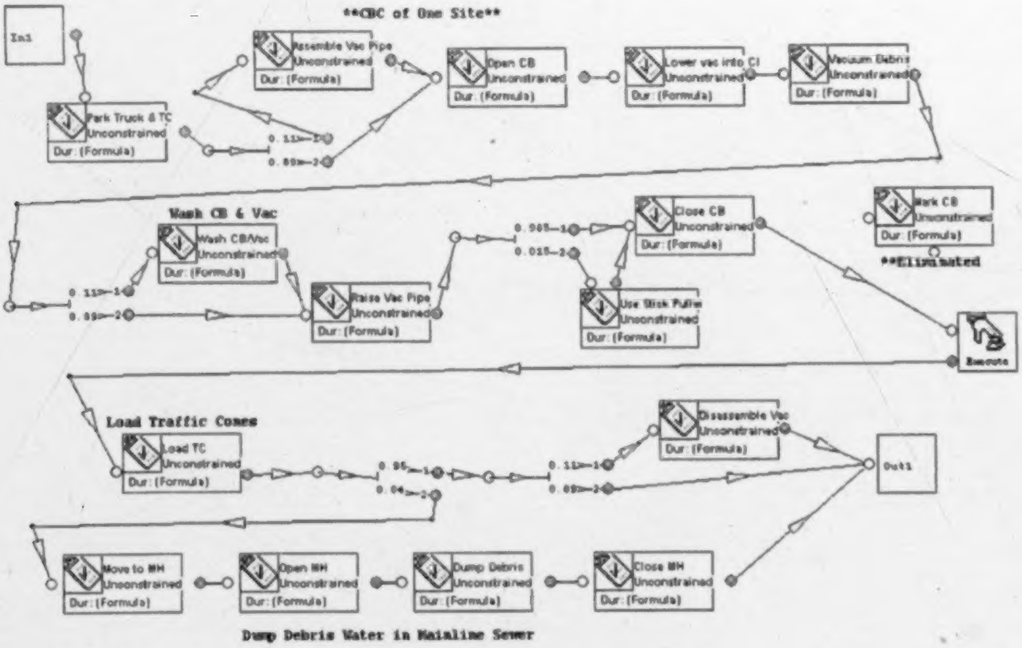

CBC of One Site
In1
Park Truck & TC
Assemble Vac Pipe
Open CB
Lower vac into CI
Vacuum Debris
Unconstrained
Dur: (Formula)
0.11>-1
0.89>-2
Wash CB & Vac
Wash CB/Vac
Raise Vac Pipe
0.985-1
0.015-2
Close CB
Use Stick Puller
Mark CB
**Eliminated
Execute
Load Traffic Cones
Load TC
0.96>-1
0.04>-2
Disassemble Vac
Out1
Move to MH
Open MH
Dump Debris
Close MH
Dump Debris Water in Mainline Sewer

Figure 59: Modified "CBC of One Site" work method

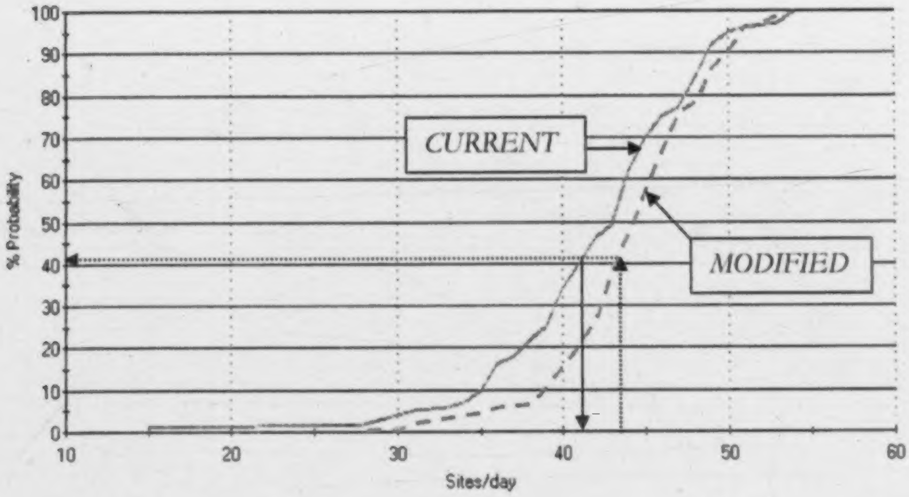


Figure 60: Cumulative distribution functions of current and modified CBC work method

Figure 61 displays the new HPF model after implementing the improvement outlined in Table 20. The modification to eliminate the "Remove Debris" task is tolerable since this element can take place at anytime during the catch basin cleaning activity of one site. Reducing the cycle time for "Lower/Position Nozzle" is achieved by either introducing a structural modification, a "lip", to an elevated entrance to a mainline or by developing a tool that would enable a crewmember to insert the hose into the mainline with ease such as a telescopic clamp or grappling pole. Assuming that it currently takes about 0.932 minutes per site (0.932 minutes*7.8 sites/day = 7.27 minutes; cycle time) to lower and position the nozzle into the mainline, an educated guess is made to reduce the cycle time down to 0.25 minutes per site (0.25 minutes*7.8 sites/day = 3.9 minutes) which is based on observing the crew over the data collection time span. In terms of an organization-wide implementation of an automated means of tracking labour timesheets, the data collected for the "Paper Work" element seem inappropriate to model due to its relatively short cycle time; it was not captured fully during the time study data collection period. After implementing the suggestions, the improvement in productivity from 594.22 meters flushed per day to 607.96 meters flushed per day is obvious. An increase of 13.74 meters flushed per day or 2.3 % proves that an enhancement of productivity proposed by the simulation model, integrating lean-thinking is possible. Figure 62 displays the difference in productivity gained before and after lean application. For instance, at a probability of 48%, the productivity is higher for the modified work method than the current work method. See Table 21 for the complete summary of results.

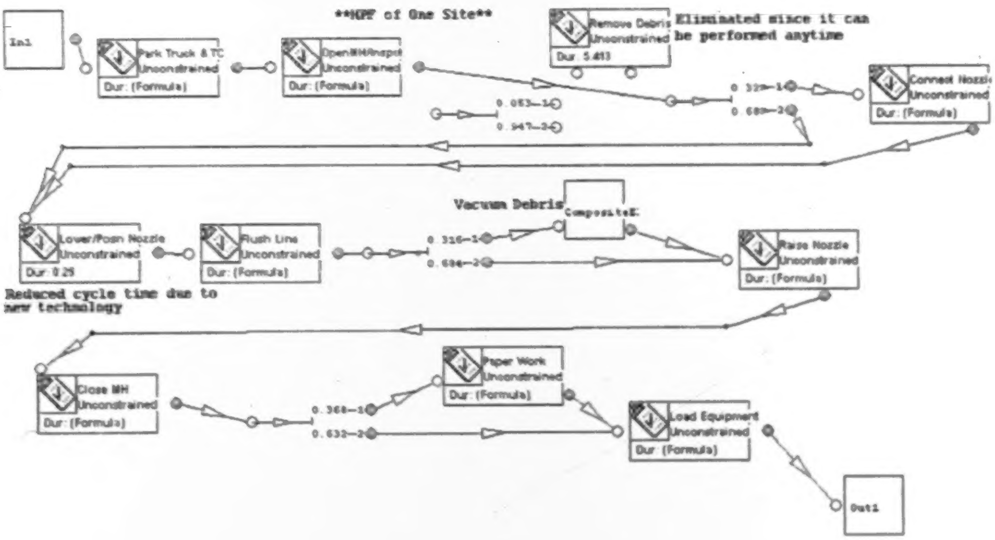

HPF of One Site
In1
Park Truck & TC
Unconstrained
Dur: (Formula)
OpenMH/Inspct
Unconstrained
Dur: (Formula)
Remove Debris
Unconstrained
Dur: 5.413
Eliminated since it can be performed anytime
0.053—1
0.947—2
0.32—1
0.68—2
Connect Nozzle
Unconstrained
Dur: (Formula)
Vacuum Debris
CompositeE:
Lower/Posn Nozzle
Unconstrained
Dur: 0.25
Reduced cycle time due to new technology
Flush Line
Unconstrained
Dur: (Formula)
0.316—1
0.684—2
Raise Nozzle
Unconstrained
Dur: (Formula)
Close MH
Unconstrained
Dur: (Formula)
0.368—1
0.632—2
Paper Work
Unconstrained
Dur: (Formula)
Load Equipment
Unconstrained
Dur: (Formula)
Out1

Figure 61: Modified "HPF of One Site" work method

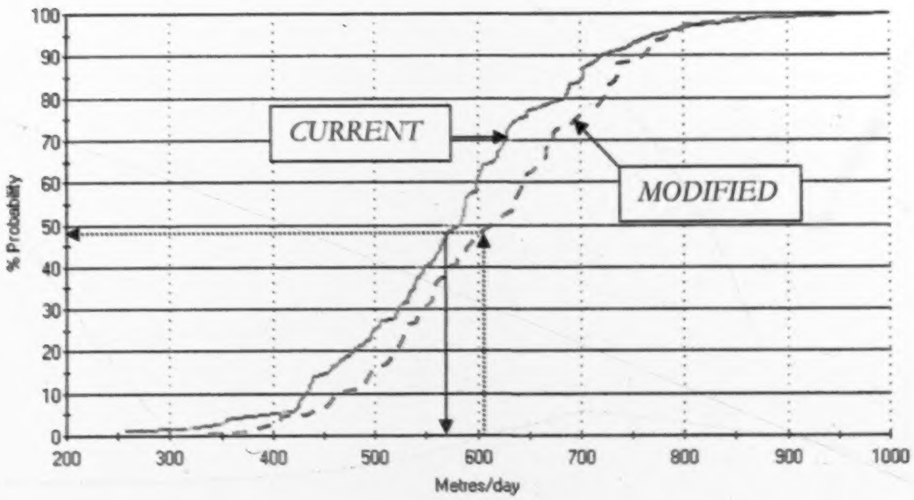


Figure 62: Cumulative distribution functions of current and modified HPF work method

4.8 SUMMARY OF RESULTS

By applying lean-thinking concepts to the general purpose simulation models, the results are summarized in Table 21. The “Historical Daily Throughput: was calculated based on an accumulated average during a 5-year period (1995 to 2000). The “Work Measurement” data is the current daily accomplishments based on a 90% confidence level and 5% precision. The “Potential % Change” is the percentage increase in productivity of the work crews. It is evident that CEI and SLR demonstrated the greatest productivity gain, and therefore, these have the highest priority over the rest of the crews in terms of further investigation by Drainage Operations management, training personnel, crewmembers, and OH & S. In addition, a cost-benefit analysis as well as organization-wide commitment and co-operation by all parties involved would be required prior to any implementation. Ultimately, the magnitude of the cost reductions (as shown in Table 13) apparent from the improvement in productivity should also be investigated to justify the need for undertaking such a study.

Table 21: Results after applying lean theory to simulation models (Agbulos et al, 2003)

PRODUCTIVITY EFFECTS SUMMARY					
CREW	***Historic Accumulated Average***	***Work Measurement***	***SIMULATION RESULTS***		
			Current Methods	***Improved Methods***	***Potential % Change***
CEI	**6.68 sites/day**	**13.18 sites/day**	**13.93 sites/day**	**16.24 sites/day**	**+ 16.6 %**
SLR	**3.66 sites/day**	**3.99 sites/day**	**3.76 sites/day**	**4.16 sites/day**	**+ 10.6 %**
CBC	**43.49 sites/day**	**40.17 sites/day**	**42.52 sites/day**	**44.25 sites/day**	**+ 4.00 %**
HPF	**525.38 m/day**	**523.39 m/day**	**580.73 m/day**	**607.96 m/day**	**+ 4.69 %**
MTV	**345.87 m/day**	**360.53 m/day**	**366.35 m/day**	**382.08 m/day**	**+ 4.29 %**

4.9 LIMITATIONS

The reality of simulation is that every scenario possible can not be accounted for. As a result, the models were developed using probability branches. Each of those branches attached to an element (or work step) was assigned a probability unless the element was assumed to occur during every cycle. That is, the chance of an activity occurring was either assumed to take place after every cycle (entire shift) of the actual maintenance work (such as mainline televising) or an element out-of-sequence that could occur at any moment (e.g. delays such as unrelated work, excessive work, idle time, personal time, productive interruption, and instruction) was assigned a probability value (percent). The models were set up in a way that work flowed as continuous as possible. In addition, some instances of the application of lean concepts to current drainage operations maintenance crews relied on assumptions. These assumptions had to be made due to either poor quality data or the data not collected at all. Having had several different analysts may have had an effect on gathering consistent results. An assumed reduction, based on judgement from observing these crews, in a work element's cycle time occurred whenever an introduction to a new technology or tool (automated labour tracking method, more versatile mainline camera, tool belt, etc.) had been suggested. Having such technologies in place may increase the accuracy of the reduction in the task's cycle time. Though the results are successful, i.e. improvements in productivity have been demonstrated by applying lean concepts and utilizing simulation as the means to achieve this, the extent of the benefits of such a study can only be experienced by implementation.

4.10 FUTURE IMPLEMENTATIONS

There are several recommendations that could benefit the Drainage Operations Maintenance Crews as a whole, but were not modeled during this study: 1) vehicle routing optimization and in some cases, 2) automated labour tracking system. These recommendations will be discussed in the following sections. A reason for not including vehicle routing optimization during the simulation analysis is that in assuming a percentage reduction, for example 50%, on a cycle time for a work step such as 'Inspect Trap/Drain' for commercial establishment investigation (CEI), seems more realistic since it takes about 2 to 3 minutes to complete the task. However, if one was to reduce the cycle time for 'Travel to 1st Site', the same reduction percentage of 50% affects the time on a greater scale since the typical time it takes to travel to the first site for CEI is about 34 minutes, which seems very optimistic. In some cases, data for completion of timesheets was insufficient and therefore, not modelled in Simphony. Thus, these items are those that would require the greatest amount of work to implement and were omitted during the simulation analyses for simplicity. The City of Edmonton management are adapting an SAP system (Systems, Applications, and Products in Data Processing), which includes a labour tracking system and an optimization program for vehicle routing.

4.10.1 OPTIMIZED VEHICLE ROUTING SYSTEM

Improvement in all travel times by developing a vehicle routing optimization system is an alternative that was not be modeled in this study. The development of such an improvement would require much time, effort, resources as well as other tools such as linear programming and heuristic theory to accomplish. Depending on the crew and how the work is assigned to them may reflect on the degree of effectiveness for a vehicle routing optimization system. Current methods utilized by the City of Edmonton's Drainage Operations Branch rely on manually assigning crews a specific frequency and area of the city to work in which were developed in the late 80's.

Currently, there are software programs such as STARS, ILOG Dispatcher, and Paragon™ that handle vehicle routing problems. STARS, (Smart Truck Assignment and Routing System), is an optimization-based vehicle routing and scheduling system that determines optimal product loadings, delivery routes and schedules of vehicles taking into account constraints imposed by vehicle operations and customers. ILOG Dispatcher is an optimization engine for creating vehicle routing and personnel scheduling and dispatching applications that allows modeling of real-life constraints like vehicle capacities, customer time windows, and work-hour regulations. Routing problems can then be modeled simply and naturally, cutting development time and cost as a result. Paragon™ has developed software to handle routing and scheduling and has proven to assist companies in effectively managing their truck fleets by reducing transportation costs by 10 – 20%.

Activities such as Commercial Establishment Investigation, Scheduled Mechanical Cleaning of Catch Basins, Inspecting Mains by Televising, and especially Cleaning Mains by High Pressure Flushing, could benefit from an optimization scheme such as those software programs have described. However, the nature of how the work is distributed to the Service Line Rodding & Televising crews may pose a problem. That is, after every site finished, a call to the immediate foreman informs the crew of the address of where the next complaint is located. In some cases, there is no call made from the public to complain about any sewer trouble at all. The dilemma is that most people are not aware of the nature of their drainage problem and therefore, having the crews respond to the predicament will provide the customer with some sort of satisfaction or comfort for the situation. The aforementioned vehicle routing and scheduling software should be investigated to verify whether or not the Service Line Rodding and Televising crews can benefit from this development. Future research within this field of study would have to be considered to enhance the travel aspect for drainage operations that the current research does not take into account. That is, once a system has been chosen and implemented, the crews will have to undergo another time study session to develop another standard. Using optimization software, one can calculate potential productivity gains using information from the original time study. Information from the optimization software on travel times can then be inputted into the simulation model to determine the effects on productivity, and therefore, a new standard can be developed.

4.10.2 AUTOMATED LABOUR TRACKING SYSTEM

Currently, the City of Edmonton's Drainage Operations Branch utilizes a manually-based timesheet system. The employees manually enter their accomplishments on paper to subsequently have the information entered into the computer by another employee. This introduces the possibility of errors during the input session as well as unnecessarily increasing the process time of the employee timesheets themselves. The development of an automated system for the crews would greatly reduce the time required to complete and process the timesheets, though this would require the crews to acquire proper training for correct use of the system. By assuming a percentage reduction in cycle time to perform "Paper Work", only an estimated time savings is evident. Implementation of this type of technology is beyond the scope of the current research and should be investigated further in subsequent studies. At the moment, an enterprise resource planning system is undergoing an organization-wide facelift called SAP (Systems, Applications, and Products in Data Processing), which is under evaluation by the City for possible adaptation. This system will integrate the information gathered from employees as well as provide indications of performance for operational activities rather than the current system where information is only quantified. For Drainage Operations, the generation of meaningful and timely performance reports for use by all operational staff could be produced.

4.11 CONCLUSIONS

This chapter investigated the current work methods employed by the City of Edmonton's Drainage Operations Maintenance crews. Lean concepts were applied to existing general purpose simulation models to improve the productivity of these crews. Identifying the waste (non-value adding) work steps (such as equipment handling), combining them with value-added work steps (all operation tasks), and reducing cycle times of several elements as a result of streamlining the current technology (such as better cameras), improvements in productivity were demonstrated using the simulation models. An asset to using the simulation models is that these suggestions and modifications to existing work methods can be applied on the PC and instant results can be obtained without having to introduce these new developments out in the field. The next step would be to approach management regarding possible implementation to field crews as was conducted with the low pressure flushing pilot crews.

The gains in productivity indicate movement in the right direction. However, the omission of modeling the delay elements could be the difference in increasing the improvement even further. Decreasing the overall delay time (non-value added elements or waste) should have a positive effect by increasing the portion of value-added tasks and consequently assisting the crews to reach an even higher productivity rate. Ensuing investigation and field implementation should validate this claim, but is outside the scope of the current research. A cost/benefit analysis would have to be carried out in order for management to decide whether progression into new technology for the productivity improvement of the drainage operations maintenance crews is feasible.

The results of an analysis of applying lean concepts to current drainage maintenance work methods using simulation are summarized in Table 21. A discussion on several limitations of the study and future recommendations for further work in this area of research revealed that areas of improvement in conducting this study (such as modelling delay elements) are evident. Figure 61 displays the total percentage of value and non-value added work elements for all drainage operations maintenance crews (except low pressure flushing). Modified ratios can only be re-calculated upon industrial implementation and performance measurement using the time study method of data collection. These help management in illustrating the status of the maintenance work crews as well as assisting them in terms of depicting possible areas of work flow improvement.

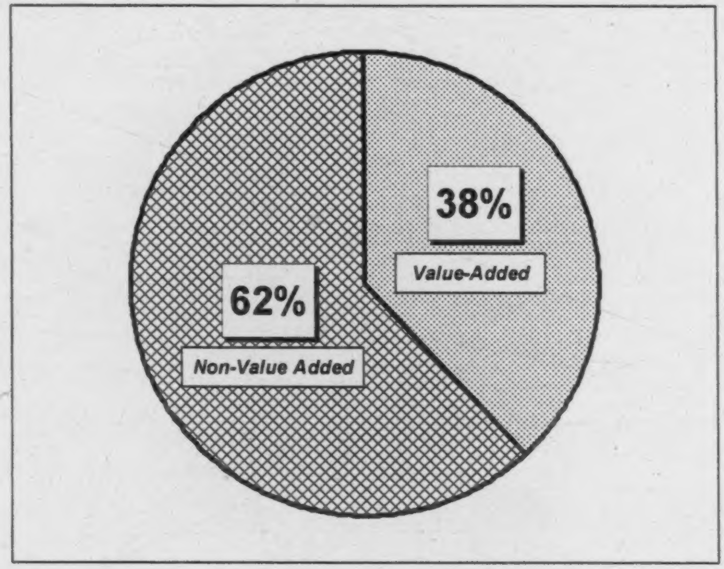


Figure 63: Overall NVA versus VA breakdown of current Drainage Operations maintenance crews

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 RESEARCH SUMMARY

The material presented in this thesis described the effectiveness in developing productivity standards as well as the framework for the application and integration of lean concepts to existing drainage operations maintenance work processes with general purpose simulation (GPS) methodology. The development of this relationship between these different philosophies is the result of motivation from a successful pilot study performed for low pressure flushing, the development of a flexible and powerful simulation engine called Simphony, and the successful collaborative research work between the City of Edmonton Drainage Operations Branch and Office of the City Auditor, and the NSERC/Alberta Construction Industry Research in Construction and Engineering Management. The main focus of the research presented in this thesis is on the Work Analysis Study which involved the data collection and analysis of the work crews. The time study, as described in Chapter 2.3 and 3.4, was the selected method of gathering data. By choosing specialized "off the shelf" time study software called Timer Palm™, this enhanced the work performance measurement process by providing an easy and effective technique in collecting the data as well as enabling for quick and accurate data analyses. Each work activity in drainage operations maintenance was observed for a full shift at a time over a 3-month period and subsequently analyzed in the development and implementation of productivity standards to the crews using spreadsheets.

Several models were modified during the data collection and simulation was used as a decision-support tool in the development of the productivity standards. Simulation was also used as the primary means of applying lean principles to current work methods for drainage operations activities. Results from the development of productivity standards demonstrated improved performance in some of the crews, namely mainline televising and service line rodding. Management believed that two of the remaining crews, commercial establishment investigation and high pressure flushing, were underachieving based on historical accomplishments; as well, this was supported through observation during the field data collection. Therefore, the established productivity standards were maintained at their current levels and did not change as a result of the underachievement of the two crews.

The detailed investigation and description of the framework for developing productivity standards as well as integrating lean theory and simulation methodology provides the tools necessary to improve labour productivity for drainage operations maintenance activities. As a result of the study, it has been recognized that assuming the crews perform to the productivity standards, actual productivity gains could range from as low as 1% to as high as 49%. The related potential cost savings could range from about $ 14, 000 to $ 91, 000 per crew which, in total, is over $ 316, 000. Apart from the research presented, the industrial application of most aspects of the research has been documented in terms of a report to the City of Edmonton as well as conference and journal papers resulting from this study. Although current time study methods are effective, the main advantage of the software selected for data collection is its low cost, simplicity, versatility, and short data processing period. Combining that with Ohno's lean mindset and using simulation to carry out those alternatives resulting from lean-thinking, the idea of being able to apply the methodology outlined in this thesis to any repetitive work process in any industry is very promising.

5.2 RECOMMENDATIONS FOR FUTURE WORK

During the course of the research work, the following has been noted as recommendations for further research and development to improve the current framework for developing productivity standards and applying lean concepts with simulation methodology as it stands.

1. Better recording system of the current productivities which are based on results from the daily accomplishments (total meters flushed/recorded, locations visited) recorded from the workers.

2. To increase the accuracy of the developed model, the general purpose simulation models for each maintenance activity should model any delay elements (personal time, unrelated work, excessive work, instruction, and productive interruption).
3. For those elements where the reduction of cycle times is based on the judgement of the analyst, it would be beneficial to acquire field data to support the assumptions emanated in the thesis. At the task level, any of the suggestions described for the drainage operations maintenance activities such as technological improvements in equipment (camera, tool belt, etc.) should be applied in real-world situations to accurately measure the actual percentage decrease in the cycle time of a particular work step.
4. Developing a vehicle optimization system and automated labour tracking system have the potential of time savings and productivity increases.
5. Quantifying the efforts by conducting a cost-benefit analysis would enhance the results.
6. Development of a global operations simulation model incorporating all existing models to maximize Drainage Operations' efficiency and effectiveness, i.e. improvement of overall operations performance.
7. Application of current research work to other construction processes may lead to significant time and cost savings.
8. Methodology behind the development of physical demands analyses presented can be adopted in construction to assess the safety and job requirements for a construction worker.

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APPENDIX A

Jan 14, 2002

Met with the HPF foreman and discussed the scheduled plan for the next week. He explained how HPF work is planned and scheduled based on the priority of the job. The priority that determines the frequency of the maintenance job to be accomplished with the exemption of emergency jobs (priority#1).

The foreman said that it is difficult to plan the crews' work beforehand. The reason is in the expectation of emergency calls they might receive. In order to save on travel, a suggestion was made to assign priority#1 jobs to special crews while others can be assigned the remaining scheduled jobs, which can be an improvement in terms of travel time and distances. It was also stated that it is better for all crews to be ready for emergencies so that the closest crew can reach the site in minimum time and distance.

Jan. 14-18

HPF operation was observed for 4 days. The first 2 days were flushing a line, which had a lot of debris and can be classified as a bad case. The following points can be noted:

Planning and Management:

- The parking lot has room for 12 combination units, but there are always 4 units having to wait for others to leave the lot.
- In high traffic areas, combination units need special traffic control and safety regulations. In some cases after their arrival to the job site, the operator has to decide if the mentioned regulations apply to the job site. So, if the regulations do not apply he will leave the worksite and go to the next scheduled job. The job where the worksite did not follow regulations has to be rescheduled for either a weekend or night shift.
- Some problems such as grease in pipes caused by restaurants or other facilities around may occur. This might need some **coordination with other agencies to minimize the cause**. Such problems need a frequency #1 or #2 HPF operation, while they can be replaced with higher frequencies (less maintenance needed).
- The tank-filling task can be done in parallel with flushing task. This depends on the followings:
    - Condition of the tank (full or not) before truck leaves the yard,
    - Accessibility of the hydrant on the site, and
    - Ability of the operator to manage.

  Operator needs instructions to better manage such a case.

Design:

- Manholes, new caps have a rubber belt, which cause some delay when the helper tries to open them.
- Aligning and directing the nozzle into the pipe might cause some delay especially when the manhole is relatively deep and the pipe is narrow. **Pipes at the manhole edge can be shaped in the way eases in aligning and directing the nozzle into the entrance of the pipe.**

Notes:

- The OMMS software gives the schedule sorted by area and frequency. (E.g. All frequency-1 jobs in area #3). The HPF foreman sorts the schedule manually by assigning a specific frequency to a specific crew but in different areas. The intent is to try and minimize travel time and distance as much possible.
- A review of all frequencies will be done (date TBA). These frequencies were set in late 80's.
- Noted from the Annual report and HPF Benchmarking in CA that:

- Production decreased by 30% from year 1996 (9 units operated) to 2000 (11 units), while cost increased by the same amount. (Page #30).
- A considerable difference between productions in CA, US and the City of Edmonton existed. CA HPF production is 4 times as much as Edmonton's. **Some factors play a role but are still worth analyzing.**

Jan 21-25

HPF

Observation	Impact	Recommendation	Benefits
The parking lot has room for 12 combination units, but there are always 4 units having to wait for others to leave the lot.	Delay for trucks to leave the yard	Instructions to be given 10 minutes ahead to either the front or back truck operators*. A suggestion that operators could drain the air break system (5 minutes) and build up the pressure (10 minutes) out of the parking shop on the job site.	This saves time for all trucks but it will not solve the waiting problem.
Some problems such as grease in pipes caused by restaurants or other facilities around may occur.	Always need frequency #1 or #2 HPF operation.	This might need more **coordination with Industrial Waste (IW) department. ****	They can be replaced with higher frequencies (less maintenance needed).
Aligning and directing the nozzle into the pipe might cause some delay especially when the manhole is relatively deep and the pipe is narrow.	5-10 minutes delay for each crew per shift.	A hard tool instead of the rope to help operator aliening the nozzle. ***	3% increase in production. If the average time for positioning nozzle element (1.71mi.) decreased by .5 min. This was tested using Simulation model.

* It is not easy to apply this recommendation. (Union-related issue).

** This was discussed with Drainage Operations manager. He focused on the fact that the role of IW inspector is more important than testing (televising or taking samples from sewer pipe). Such a role can better control the disposal of grease and other prevented materials into sewer lines. Televising and sampling are not enough evidence to prove that the restaurant is responsible for such disposal.

*** A meeting with Lynn and Michael (pump well manager) on Monday, Jan. 28 to discuss the issue.

Observation	Impact	Recommendation	Benefits
The OMMS software gives the schedule sorted by area and frequency. (E.g. All friquency-1 jobs in area #3). The HPF foreman sorts the schedule manually by assigning a specific frequency to a specific crew but in different areas. He tries to minimize travel time and distance as much possible.	Delay in travel time. *	Optimization model taking into consideration number of trucks, frequency distributions, and other constraints.	Minimizing travel time. This could apply to other fleets such as LPF and others.
Instructions, inspection, travel to the first site on one hand and coming back to the yard and dumping on the other hand, all take about 25% of shift time every day (2 out of 8 hours).	Usual production	Make shift 10 hours a day keeping 40 hours working per week. **	Activities mentioned would take about 20% of shift time (2 out of 10 hours)' which means a 5% increase in production

* More verification needed.

** This has many constraints (union) and it involves major changes, however it may be worth consideration.

Jan 21-25

HPF cont'd

On Friday Feb 1^{st}, a meeting to discuss the idea of a 10X4 hour work week. Reliable data is needed for productivity to be calculated and compared in both 10X4 and 8X5 work weeks. The problem of scheduling work for night shifts was discussed and solutions were suggested as well. Other constraints will be analyzed later.

MTV

Observation	Impact	Recommendation	Benefits
The same problem (mentioned in HPF) regarding the parking lot since the parking lot is used for both HPF and MTV trucks.	Delay for trucks to leave the yard	No suggestion yet.	
It takes from 10 to 15 minutes to adjust the skid size for the Camera every time. Such an element is needed twice a day on average.	Causes delay when HPF nozzle has already reached the manhole.	Changing the used tool to another one that has adjustable plates to enable the operator (or helper) to change camera skids faster.	It reduces the time of the element to less than 5 minutes*.
The blower is laid on the floor of MTV truck from inside the truck to the manhole outside through the back door.	It takes a considerable amount of space in the truck. This obstructs the movement of the operator and helper.	Transferring one of the heat openings to outside of the truck (opening to be on the back just beside the door) in a way so that the blower can be connected directly from the opening to the manhole and is completely outside.	Facilitates for better movement in the truck and improved usage of space inside the truck **.

Observation	Impact	Recommendation	Benefits
In some cases, the nozzle arrives at the manhole before the operator has prepared the camera to be lowered into the manhole. In those cases, the HPF operator and helper have to wait for the MTV operator to finish and lower the camera ***.	Ideal time for both operator and helper.	Training the helper to prepare the camera and have the MTV operator check it before lowering it down.	It reduces the ideal time and gives more flexibility to the crew.

* Discussed the idea with Training Officer on Wednesday, Jan 30th. He said he would work on it in the next week.

** Pump well manager will be notified because they are assembling new MTV equipment.

*** This depends on many factors such as:

- The time they leave the yard (MTV and HPF trucks)
- The travel time for both. (HPF truck limited to special roads)
- The ability of MTV operator to plan and manage the work process in cooperation with HPF operator.

February 11-22

SLV & SLR

Notes were cited and discussed in the meeting on February 20th. Additional recommendations are discussed in the following table:

Observation	Impact	Recommendation	Benefits
Problem of non-action (inside plumbing) performance activities (PA) was discussed (99 PAs for January 2002).	99*12=1188 PA s if each takes 1 hour while 1 hour cost $75 (a crew of 2 + overhead) the ` annual cost will be: 75*1188 = **$89100/year**	1-Provide training to the dispatcher in plumping area (it may require a course) 2-Have the dispatcher goes with the SLT&R crews for a week or more. 3-Develop a set of questions to better help distinguishing between inside plumping and SL problems. (A committee of SLT&R operator, dispatcher, and a supervisor can develop such questions). 4- If possible, informing the homeowner that there is a charge (about $10) if it is inside plumbing problem. By this the homeowner will pay more attention to questions. (The $10 charge by itself will save about 13% annually or $11800/year). 5- Have phone calls monitored for potential improvement in future.	More control will decrease the annual cost of non-action PA s.

IWI

Observation	Impact	Recommendation	Benefits
Managers and workers (not owners) in some of restaurants have no idea what the purpose of proper disposal of oil and grease.	No motive to cooperate with the city to minimize the impact of oil, grease, and others on the sewer network (the only motive is to avoid the fine)	Information sheet to be handed to every restaurant and hanged on the wall in the kitchen. Such a sheet can include simple instructions supported with pictures. It also can include an idea of the impact in terms of cost and time on the private and city sewer lines. Environmental impacts can be cited as well.	More cooperation with the City of Edmonton based on positive motive (sharing responsibility with the city in maintaining the infrastructure and environment).
The inspector spends some time to locate the manhole and to fill out note sheets (a sheet for every site).	Delay	Laptop for maps and note sheets needed.	Saves time and eases noting and reporting*.
Manhole inspection during IWI work is not reported.	Another crew will inspect the manholes visually. (Work duplication).	IW inspector to report manholes inspected and data to be send to visual inspection section.	Avoid duplication*.
Long travel time from the yard to first site and from the last site to the yard (especially, for west end and south crews)	Delay	4X10 shift	Save time**

*In general there is a weakness in data flow among sections this relates to the following:

- Paper work method is still used to report data by operators (HPF, MTV, IWI, and others). These papers are handed every shift's end to foremen then to technicians and managers to be processed and analyzed later (With exception to videotapes).

- Sections (HPF, MTV, SLV&R, IWI, and others) are not viewed as a system (to an extent). A system that requires faster data exchange and flow, where data can be better utilized.

** IWI and SLV&R schedules have no constraints as HPF and MTV schedules do. While in IWI case the 10X4 shift helps in inspecting restaurants that open only after 3:00 PM.